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ANNUAL MEETING, MAY 21, page 193.

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OF THE
American Institute
OF
Electrical Engineers

Volume XXXI
Number 5

MAY, 1912

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PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

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GEORGE R. METCALFE, Editor

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Vol XXXI **January, 1912** No. 1

Next Regular Meeting, A. I. E. E., New York, January 12, 1912

The 267th meeting of the American Institute of Electrical Engineers will be held in the Auditorium of the Engineers' Building, 33 West 39th Street, New York, on Friday, January 13, 1912. A paper entitled "Some Notes on Isolated Plants" will be presented by Mr. Percival R. Moses, Consulting Engineer, of New York City.

The success of the smoker held at ten o'clock on the evening of the last meeting of the Institute after the closure of the discussion on the paper, has lead the Meetings and Papers Committee to decide to continue these functions and there will be one after the coming meeting on Friday, January 12, at the close of the portion of the meeting devoted to the presentation and discussion of Mr. Moses' paper. The meeting will open punctually in order that the discussion may be closed at ten o'clock.

Nominations. Important Modification

At the meeting of the Institute Board of Directors held December 8, 1911, the President brought up again the modification in the method of making nominations which had been presented to the meeting of Section officers at the Chicago convention, which modification had been formulated by Acting Secretary Hutchinson. He called attention to the desirability of adding to the present system of nominating officers the feature of advance nomination by petition, so that when the nominating forms go out on February 1st the members will have some guide as to possible candidates, with the result of a concentration in what is at present the extremely large scattering vote. So large has been the scattering vote in connection with nominations for Manager that last year it was distributed among 581 different candidates, and as a result of such scattering the Manager heading the list, received only 4.8 per cent of the vote of the membership. The addition to the present nominating system consists merely in publishing at the time the nominating ballots go out the names of all candidates in favor of whom a petition of fifty names, or the separate endorsement of fifty names, has been received at Institute headquarters by January 25. The proposed plan involved the adoption of the following substitution for Section 18 of the existing by-laws:

> "In addition to the names of the incumbents of office, the Secretary shall publish on the 'form showing offices to be filled at the ensuing annual election in May', provided for in Article VI, Section 30, of the constitution, the names, as candidates for nomination, of such members and associates of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty Members or Associates, received by the Secretary of the Institute in writing by January 25 of each year.
>
> "The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the January issue of each year's PROCEEDINGS and shall be reproduced on the form above referred to."

The Board adopted the following resolution, thereby approving the proposed modification:

Resolved, that the foregoing proposed by-law providing for certain modifications to the present method of nominating Institute officers be adopted as read, as a substitute for the present Section 18 of the Institute by-laws.

The attention of all members is hereby called to the fact that, as indicated above, petitions or separate endorsements of candidates must be received at Institute headquarters not later than January 25. Copies of a petition form may be obtained upon application to Institute headquarters, but the form is not necessary as endorsement may be made by letter.

Further information regarding the plan described above, will be found on page 121 of this issue in the report of President Dunn's remarks at the conference of Institute officers and Section delegates, held during the Chicago Convention in June, 1911.

A. I. E. E. Annual Convention

As announced elsewhere in this issue, it was decided at the December meeting of the Board of Directors to hold the 1912 Annual Convention at Boston, Mass., during the latter part of June. At a subsequent meeting of the Meetings and Papers Committee, to which the matter was referred, the dates of the convention have been fixed for June 25 to 28 inclusive. It is thirteen years since the Annual Convention was held in Boston, and owing to the large number of Institute members residing in the New England territory and the direct railroad connections with many important cities, an unusually large attendance is anticipated.

The Meetings and Papers Committee is already actively engaged in preparing a programme of technical papers to be presented at this convention and it is earnestly requested that all members desiring to present papers submit manuscripts to the committee for approval at the earliest opportunity, in order to allow sufficient time for their preparation and printing in the May and June PROCEEDINGS. All manuscripts should be received at the Institute Headquarters before April 1, and if not received before April 15 their publication in advance of the meeting cannot be guaranteed.

Panama Trip

Arrangements for the Institute trip to Panama have been practically completed. Over one hundred applications for reservations were received from members and guests of the Institute up to December 20.

The schedule of the two steamers is as follows:

STEAMER "ALMIRANTE"

Leave New York	Wednesday,	Jan.	17–12 noon
Arrive Port Antonio	Monday,	"	22– 6 A.M.
Leave Port Antonio	"	"	22– 8 A.M.
Arrive Kingston	"	"	22– 2 P.M.
Leave Kingston	Tuesday,	"	23– 6 P.M.
Arrive Colon	Thursday,	"	25–12 noon
Leave Colon	Friday,	"	26– 5 P.M.
Arrive Santa Marta	Sunday,	"	28– 6 A.M.
Leave Santa Marta	Tuesday,	"	30– 5 P.M.
Arrive Colon	Thursday,	Feb.	1– 7 A.M.
Leave Colon	"	"	1–11 A.M.
for New York, via Kingston and Port Antonio.			
Arrives New York	Thursday,	Feb.	8– 2 P.M.

STEAMER "PARISMINA"

Leave New Orleans	Saturday,	Jan.	20–11 A.M.
Arrive Colon	Thursday,	"	25– 7 A.M.
Leave Colon	Monday,	"	29– 5 P.M.
Arrive Bocas del Toro	Tuesday	"	30– 6 A.M.
Leave Bocas del Toro	Wednesday	"	31– 6 P.M.
Arrive Colon	Thursday,	Feb.	1– 6 A.M.
Leave Colon	"	"	1– 3 P.M.
Arrive New Orleans	Tuesday,	"	6– 6 A.M.

Details of the stay while on the Isthmus are being arranged by Mr. Edward Schildhauer, who is a member of the Panama Trip Committee and who is located on the Isthmus.

The committee has succeeded in obtaining special rates for the Institute party at the Hotel Tivoli while at Panama, these rates being $3.50 to $4.00 per day, American plan.

A circular including information regarding baggage, desirable wearing apparel and other details will be mailed about January 1 to all members and guests who intend to participate in the trip.

In accordance with the agreement

with the steamship company, as previously outlined in the circular of November 18 and in the December issue of the PROCEEDINGS, all reservations and remittances received at the Institute offices have now been turned over to the company, and any further correspondence regarding reservations should be conducted directly with the United Fruit Company, 17 Battery Place, New York City.

Resume of Business Transacted at the Meeting of the Board of Directors of the A.I.E.E., December 8, 1911

The regular monthly meeting of the Board of Directors of the Institute was held in New York on Friday afternoon, December 8. The following directors were present: President Gano Dunn, New York, Vice-Presidents Morgan Brooks, Urbana, Ill., H. W. Buck, Percy H. Thomas and W. G. Carlton, New York, David B. Rushmore, Schenectady, N. Y., Managers A. W. Berresford, Milwaukee, Wis., S. D. Sprong and W. S. Rugg, New York, F. S. Hunting, Fort Wayne, Ind., Farley Osgood, Newark, N. J., Treasurer George A. Hamilton, Elizabeth, N. J., and Acting Secretary F. L. Hutchinson, New York.

Upon recommendation of the Meetings and Papers Committee, it was

Resolved, that the Annual Convention be held in Boston during the latter part of June, 1912, the exact dates to be determined by the Meetings and Papers Committee.

The committee also recommended a meeting of the High Tension Transmission Committee in New York on March 8, a railway meeting in New York on April 5, and an industrial power meeting in Pittsburgh under the auspices of the Pittsburgh Section of the A. I. E. E., on April 25, 26 and 27, 1911, in consequence of which the following resolutions were adopted:

Resolved, that the date of the April Institute meeting in New York, also the date of the April meeting of the Board of Directors, be advanced one week, making the date of these meetings April 5 instead of April 12, and that due notice to this effect be sent out to the membership in regular course.

Resolved, that the Board of Directors approves the tentative plan of the Meetings and Papers Committee to hold an industrial power meeting in Pittsburgh on April 25, 26 and 27, 1912, under the auspices of the Pittsburgh Section.

At the November meeting of the Board an appropriation of $50.00 per meeting was authorized to defray the social expenses of the New York smokers, which are to be held each month after the reading and discussion of the paper of the evening. It was considered that this appropriation might set a precedent for the paying of social expenses from Institute funds, and the following resolutions were therefore adopted:

Resolved, that the Board of Directors finds it undesirable to make an appropriation for the social expenses of the New York meetings and hereby rescinds its action of November 10, at which such appropriation was authorized, and be it therefore

Resolved, that the chairman of the Meetings and Papers Committee is hereby authorized to appoint a reception committee to contribute to the success of the social part of the New York meetings and to receive voluntary subscriptions to defray the expenses involved.

Monthly bills of $5,830.37 were approved by the Finance Committee and ordered paid.

Upon recommendation of the Board of Examiners, 68 Associates were elected, 110 students enrolled, and Messrs. Frederick B. Brown, Allard Smith, Joseph N. G. Nesbit, Edwin H. Colpitts, Samuel G. Rhodes, and Walton Clark, were transferred to the grade of Member.

The amendment to the Constitution providing for the election of the Secretary of the Institute by the Board, which failed last year because it received only 71 per cent of the vote cast, whereas 75 per cent was necessary, was again discussed. The Board decided to resubmit this amendment to the membership because of the large majority in favor of it and because its failure to receive the necessary three quarters majority last year was considered to have been due to some misunderstanding.

The President brought up again the modification in the method of making nominations which he had presented to the meeting of Section officers at the Chicago Convention, which modification had been formulated by Acting Secretary Hutchinson. He called attention to the desirability of adding to the present system of nominating officers, the feature of advance nomination by petition, so that when the nominating forms go out on the first of February the members will have some guide as to possible candidates with the result of a concentration in what is at present the extremely large scattering vote. So large has been the scattering vote in connection with nominations for Manager that last year it was distributed among 581 different candidates, and as result of the dissipation of the vote the Manager that headed the list received only 4.8 per cent of the vote of the membership. The addition to the present nominating system consists merely in publishing at the time the nominating ballots go out the names of all candidates in favor of whom a petition of fifty names, or the separate endorsement of fifty names, have been received at Institute headquarters prior to January 25. The arrangement is enacted by a new by-law in place of Section 18 of the present by-laws and is as follows:

SEC. 18. In addition to the names of the incumbents of office, the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May" provided for in Article VI, Section 30, of the Constitution, the names, as candidates for nomination, of such Members and Associates of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty Members or Associates, received by the Secretary of the Institute in writing by January twenty-fifth of each year.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed and this by-law shall be reprinted prominently in the January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to.

It was,

Resolved, that the foregoing proposed by-law providing for certain modifications to the present method of nominating Institute officers be adopted as read, as a substitute for the present Section 18 of the Institute by-laws.

The Public Policy Committee reported that its Chairman, and Messrs. Stillwell, Townley, Finney, and President Dunn, had presented to the National Waterways Commission at Washington, D. C., on November 21 and 22, the brief on water-powers prepared by the committee, and that the Institute representation had been most successful and had added to the Institute's standing and prestige; that the water-power report had been published in the electrical press and that request for additional copies had been constantly coming in so that two new editions had to be published.

On recommendation of the Historical Museum Committee the Institute expressed its thanks to Mrs. Sidney Short in the following resolution:

Whereas, a bronze bust of our late member, Mr. Sidney Short, has been presented to the American Institute of Electrical Engineers by his widow, be it therefore

Resolved, that the Board of Directors hereby expresses its appreciation of the gift, and accepts it in grateful memory of the personal qualities and distinguished accomplishments of an early member of the Institute who contributed to many electrical arts as an inventor and to the development of electrical engineering in the United States and in Great Britain.

The Panama Committee reported most successful arrangements for two steamers to the Isthmus, one from New York on January 17, and another from New Orleans on January 20, and that although they were rapidly being taken up, there were still a few accommodations available.

On recommendation of the President, the following provision was made about an official head for the party.

Whereas, the President of the Institute is unable to go to the Isthmus of Panama with the visiting delegation of the American Institute of Electrical Engineers, and

Whereas, it is desirable that the party have a head to represent the Institute in official functions, and otherwise, as it would be represented by its President, be it therefore

Resolved, on recommendation of the President, that Manager S. D. Sprong be and he hereby is, designated the official representative of the

American Institute of Electrical Engineers in connection with the visit to the Isthmus of Panama.

In the last few years so many matters have come up of interest to the four great engineering societies as a whole, that lack of an effective cooperation between them has been felt. In order to secure this and on the suggestion of Col. Meier, past-president of the American Society of Mechanical Engineers, President Dunn recommended that the Board of Directors authorize a conference committee to deal with inter-society matters and the Board adopted this recommendation in the following resolution:

Resolved, that the President is authorized to designate the chairman and one other member of the Public Policy Committee as members on the part of the American Institute of Electrical Engineers of a joint conference committee of the engineering societies. The duty of the members of the conference committee shall be to meet and confer with corresponding members from the other societies on the call of any one of them and to inform the Board of Directors of the American Institute of Electrical Engineers of matters that it has been decided are of interest to the group of national engineering societies as a whole and to make such recommendations as the conferees think advisable to guide the action of the American Institute of Electrical Engineers.

President Dunn asked the Board to authorize him to communicate with the leading foreign electrical engineering societies with reference to the mutual establishment of visiting member privileges, so that members of the American Institute of Electrical Engineers visiting foreign countries, by the presentation of proper credentials from the Secretary, might have the privilege of temporary membership in the society of the foreign country, and in return members of foreign electrical engineering societies visiting the United States might have the privileges of the facilities afforded by the American Institute of Electrical Engineers in New York and in other cities of the United States, these visiting member privileges to be in the nature of guest privileges in a club, and in addition to the convenience they would afford mutually to members of the electrical engineering profession all over the world, to serve as a bond of friendship and inducement to more frequent intercourse among electrical engineers. The Board authorized the President to learn the attitude of the foreign electrical engineering societies toward such privileges, in the following resolution:

Resolved, that the President is authorized to communicate with certain leading foreign electrical engineering societies with respect to establishing mutual visiting member privileges for a limited term with the end in view of contributing to the convenience of our own members visiting foreign countries and in return of affording facilities to members of foreign electrical engineering societies visiting the United States.

The chairman of the Intermediate Grade of Membership Committee presented amendments to the Constitution providing for an additional grade of membership in the Institute. The features of the plan are: First. Making three grades of membership where there are now two. Second. Arranging that the highest grade shall be slightly higher than the present grade of Member, and that practically all the present Members shall be automatically transferred thereto. Third. Arranging that the intermediate grade shall be somewhat lower than the present grade of Member, and that such of the Associates, who now number 90 per cent of the Institute membership, shall be automatically transferred thereto as whose records on file justify this, the expectation being that about half of the present Associates will thereby become Members. Fourth. The giving to the vote of such Associates as shall be transferred, and to the vote of such members as are in the highest grade, an increased weight. Fifth. The status of those who remain Associates to be exactly as at present. The names for the three grades have not been finally decided, but those suggested are, for the highest grade, " Fellow ", for the next grade, " Member ", and for the third grade, " Associate." The Institute is the only large engineering society whose membership is limited to two grades, and the fact that only 10 per cent of the membership of the Institute is in its first grade, which is called that of "Member", and which prevents the use of the name Member by a very large proportion of the membership of the Institute, is an anomaly. The movement to establish an additional grade of membership is one that has already taken place in all the great engineering societies in response to the demand of their membership, and it is felt that the present amendments, if adopted, will add greatly to the Institute's solidarity. The Board of Directors provisionally adopted the amendments, and will consider them for final adoption at its next meeting, the committee in the meantime being authorized to make recommendations for modifications in detail.

On recommendation of the Standards Committee the following resolution was passed:

> *Resolved*, that the Board of Directors of the American Institute of Electrical Engineers regards as desirable the more general adoption of the international metric system of weights and measures in the engineering literature of English speaking countries, and
>
> *Resolved*, that in all papers, reports and publications of the American Institute of Electrical Engineers measures expressed otherwise than in the metric system should be accompanied by metric equivalents in parentheses, and that all of the Institute's committees affected be directed to carry this out.

The Standards Committee reported that it had appointed Dr. C. P. Steinmetz and Mr. B. G. Lamme a subcommittee to collect material looking to the next revision of the Standardization Rules.

The committee on relations of consulting engineers to manufacturing companies and others reported progress.

The Library Committee reported that Dr. Samuel Sheldon had been appointed its representative on the Library Conference Committee, and that it was considering specific means of extending the usefulness of the library to non-resident members.

The Electrochemical Committee has arranged for an electrochemical session during the Annual Convention in June.

The Committee on Indexing TRANSACTIONS of the Institute reported the completion of synopses of five years' TRANSACTIONS.

The Code Committee is at work on the question of grounding secondary circuits.

Three meetings have been held, by the Code of Ethics Committee. A rough draft of a new code has been completed and will come up for final discussion at the committee's next meeting, after which it will be sent out for the opinion and revision of the advisory members appointed by the President after the last meeting of the Board.

The Railway Committee reported particular interest in railway subjects, and that it was organizing a special meeting for April 5, which on account of the large amount of matter to be presented would probably require an afternoon session in addition to the evening one.

The President announced the following committee appointments: Educational Committee, Professor John Price Jackson, Chairman, vice Professor A. S. Langsdorf, resigned.

Representatives of the Institute upon the Council of the American Association for the Advancement of Science: Dr. J. B. Whitehead and Dr. Edward B. Rosa.

Representatives of the Institute upon the Resuscitation Commission: Dr. A. E. Kennelly and Dr. Elihu Thomson.

Membership Committee: C. E. Scribner, Chairman, S. B. Charters, Henry Floy, George W. Lamke, A. A. Miller, N. J. Neall, K. C. Randall, David B. Rushmore, A. M. Schoen, H. Clyde Snook, H. B. Stabler, and J. G. Wray.

Advisory Members to Code of Ethics Committee: Messrs. W. S. Barstow, Louis Bell, John J. Carty, F. B. Crocker, D. C. Jackson, A. E. Kennelly, John W. Lieb, Jr., C. O. Mailloux, Ralph D. Mershon, H. H. Norris, Ralph W. Pope, Harris J. Ryan, Charles F. Scott, Samuel Sheldon, William Stanley, Lewis

B. Stillwell, Elihu Thomson, and William D. Weaver.

Addition to Power Station Committee: Clyde D. Gray.

Delegate to Eighth International Congress of Applied Chemistry, September, 1912: Charles A. Doremus.

Washington Section Meeting

WASHINGTON, D. C.

The January meeting of the Washington Section will be held in the Telephone Building, Washington, on Tuesday, January 9. A paper of much local interest will be read by Mr. John H. Hanna, of Washington. Mr. Hanna is the chief engineer of the Capital Traction Company, and he will give a full description of the new steam turbine generating station which that company has recently erected on the Potomac River in Georgetown. *H. B. Stabler, Secretary, 722 12th Street, N. W., Washington.*

A. I. E. E. Meeting in New York, December 8, 1911

The 266th meeting of the American Institute of Electrical Engineers was held in the Engineers' Building, December 8, 1911. President Gano Dunn called the meeting to order at 8:25 p.m. and introduced Mr. Gus A. Maier, the speaker of the evening who abstracted his paper on " Methods of Varying the Speed of Alternating-Current Motors." The paper was discussed by Messrs. H. W. Buck, W. N. Smith, C. J. Fechheimer, B. G. Lamme, C. P. Steinmetz, C. O. Mailloux and G. A. Maier. At the close of the discussion a vote of thanks was tendered to the author for his interesting paper and the technical session adjourned.

Practically all of those present at the technical session, numbering nearly 400, gathered in the Institute offices on the 10th floor to enjoy an informal social function. Cigars were passed around and light refreshments served, while old acquaintances were renewed and new ones formed. The success of this innovation was reflected in the attendance which was nearly double the average at former meetings.

Associates Transferred on December 8, 1911

The following Associates were transferred to the grade of Member in the Institute at the meeting of the Board of Directors held on December 8, 1911:

FREDERICK B. BROWN, Consulting Engineer, Montreal, P. Q.

ALLARD SMITH, Outside Plant Engineer, Chicago Telephone Company, Chicago, Ill.

JOSEPH N. G. NESBIT, Professor of Experimental Engineering, Georgia School of Technology, Atlanta, Ga.

EDWIN H. COLPITTS, Electrical Engineer, Western Electric Company, New York.

SAMUEL G. RHODES, Engineer, Meter and Test Dept., and Supt., Arc Lamp Dept., New York Edison Company, New York.

WALTON CLARK, Third Vice-President, United Gas Improvement Company, Philadelphia, Pa.

Associates Elected December 8, 1911

ADAMS, PATRICK HENRY, Field Engineer, Public Service Electric Co., Newark; res., 80 Sussex Ave., E. Orange, N. J.

AGEE, HOWARD HIBBS, Electrical Draughtsman, Power Construction Co., Shelburne Falls, Mass.

ALDEN, VERN E., Student Apprentice, Westinghouse Electric & Mfg. Co., Pittsburg; res., 420 West St., Wilkinsburg, Pa.

ALTES, WILLEM CORNELIUS KORTHALS, Electrical Engineer, Induction Motor Engineering Dept., General Electric Co., Schenectady, N. Y.

ANDERSON, JAMES, Testing Department General Electric Company, 11 Congress St., Lynn, Mass.

ANDREWS, ARTHUR SIDNEY, Electrical Engineer, W. L. McKenzie & Co., 3rd Ave., Lethbridge, Alta.

cent of the membership of the Institute is in its first grade, which is called that of " Member ", and which prevents the use of the name Member by a very large proportion of the membership of the Institute, is an anomaly. The movement to establish an additional grade of membership is one that has already taken place in all the great engineering societies in response to the demand of their membership, and it is felt that the present amendments, if adopted, will add greatly to the Institute's solidarity. The Board of Directors provisionally adopted the amendments, and will consider them for final adoption at its next meeting, the committee in the meantime being authorized to make recommendations for modifications in detail.

On recommendation of the Standards Committee the following resolution was passed:

Resolved, that the Board of Directors of the American Institute of Electrical Engineers regards as desirable the more general adoption of the international metric system of weights and measures in the engineering literature of English speaking countries, and

Resolved, that in all papers, reports and publications of the American Institute of Electrical Engineers measures expressed otherwise than in the metric system should be accompanied by metric equivalents in parentheses, and that all of the Institute's committees affected be directed to carry this out.

The Standards Committee reported that it had appointed Dr. C. P. Steinmetz and Mr. B. G. Lamme a sub-committee to collect material looking to the next revision of the Standardization Rules.

The committee on relations of consulting engineers to manufacturing companies and others reported progress.

The Library Committee reported that Dr. Samuel Sheldon had been appointed its representative on the Library Conference Committee, and that it was considering specific means of extending the usefulness of the library to non-resident members.

The Electrochemical Committee has arranged for an electrochemical session during the Annual Convention in June.

The Committee on Indexing TRANSACTIONS of the Institute reported the completion of synopses of five years' TRANSACTIONS.

The Code Committee is at work on the question of grounding secondary circuits.

Three meetings have been held, by the Code of Ethics Committee. A rough draft of a new code has been completed and will come up for final discussion at the committee's next meeting, after which it will be sent out for the opinion and revision of the advisory members appointed by the President after the last meeting of the Board.

The Railway Committee reported particular interest in railway subjects, and that it was organizing a special meeting for April 5, which on account of the large amount of matter to be presented would probably require an afternoon session in addition to the evening one.

The President announced the following committee appointments: Educational Committee, Professor John Price Jackson, Chairman, vice Professor A. S. Langsdorf, resigned.

Representatives of the Institute upon the Council of the American Association for the Advancement of Science: Dr. J. B. Whitehead and Dr. Edward B. Rosa.

Representatives of the Institute upon the Resuscitation Commission: Dr. A. E. Kennelly and Dr. Elihu Thomson.

Membership Committee: C. E. Scribner, Chairman, S. B. Charters, Henry Floy, George W. Lamke, A. A. Miller, N. J. Neall, K. C. Randall, David B. Rushmore, A. M. Schoen, H. Clyde Snook, H. B. Stabler, and J. G. Wray.

Advisory Members to Code of Ethics Committee: Messrs. W. S. Barstow, Louis Bell, John J. Carty, F. B. Crocker, D. C. Jackson, A. E. Kennelly, John W. Lieb, Jr., C. O. Mailloux, Ralph D. Mershon, H. H. Norris, Ralph W. Pope, Harris J. Ryan, Charles F. Scott, Samuel Sheldon, William Stanley, Lewis

B. Stillwell, Elihu Thomson, and William D. Weaver.

Addition to Power Station Committee: Clyde D. Gray.

Delegate to Eighth International Congress of Applied Chemistry, September, 1912: Charles A. Doremus.

Washington Section Meeting

WASHINGTON, D. C.

The January meeting of the Washington Section will be held in the Telephone Building, Washington, on Tuesday, January 9. A paper of much local interest will be read by Mr. John H. Hanna, of Washington. Mr. Hanna is the chief engineer of the Capital Traction Company, and he will give a full description of the new steam turbine generating station which that company has recently erected on the Potomac River in Georgetown. *H. B. Stabler, Secretary*, 722 12*th Street, N. W., Washington.*

A. I. E. E. Meeting in New York, December 8, 1911

The 266th meeting of the American Institute of Electrical Engineers was held in the Engineers' Building, December 8, 1911. President Gano Dunn called the meeting to order at 8:25 p.m. and introduced Mr. Gus A. Maier, the speaker of the evening who abstracted his paper on " Methods of Varying the Speed of Alternating-Current Motors." The paper was discussed by Messrs. H. W. Buck, W. N. Smith, C. J. Fechheimer, B. G. Lamme, C. P. Steinmetz, C. O. Mailloux and G. A. Maier. At the close of the discussion a vote of thanks was tendered to the author for his interesting paper and the technical session adjourned.

Practically all of those present at the technical session, numbering nearly 400, gathered in the Institute offices on the 10th floor to enjoy an informal social function. Cigars were passed around and light refreshments served, while old acquaintances were renewed and new ones formed. The success of this innovation was reflected in the attendance which was nearly double the average at former meetings.

Associates Transferred on December 8, 1911

The following Associates were transferred to the grade of Member in the Institute at the meeting of the Board of Directors held on December 8, 1911:

FREDERICK B. BROWN, Consulting Engineer, Montreal, P. Q.

ALLARD SMITH, Outside Plant Engineer, Chicago Telephone Company, Chicago, Ill.

JOSEPH N. G. NESBIT, Professor of Experimental Engineering, Georgia School of Technology, Atlanta, Ga.

EDWIN H. COLPITTS, Electrical Engineer, Western Electric Company, New York.

SAMUEL G. RHODES, Engineer, Meter and Test Dept., and Supt., Arc Lamp Dept., New York Edison Company, New York.

WALTON CLARK, Third Vice-President, United Gas Improvement Company, Philadelphia, Pa.

Associates Elected December 8, 1911

ADAMS, PATRICK HENRY, Field Engineer, Public Service Electric Co., Newark; res., 80 Sussex Ave., E. Orange, N. J.

AGEE, HOWARD HIBBS, Electrical Draughtsman, Power Construction Co., Shelburne Falls, Mass.

ALDEN, VERN E., Student Apprentice, Westinghouse Electric & Mfg. Co., Pittsburg; res., 420 West St., Wilkinsburg, Pa.

ALTES, WILLEM CORNELIUS KORTHALS, Electrical Engineer, Induction Motor Engineering Dept., General Electric Co., Schenectady, N. Y.

ANDERSON, JAMES, Testing Department General Electric Company, 11 Congress St., Lynn, Mass.

ANDREWS, ARTHUR SIDNEY, Electrical Engineer, W. L. McKenzie & Co., 3rd Ave., Lethbridge, Alta.

Bang, Axel Frederik, Electrical Engineer, Pennsylvania Water and Power Co., U. S. Fidelity & Guaranty Bldg., Baltimore, Md.

Benedict, Edgar Ells, Sales Engineer, 6074 Stoney Island Ave., Chicago, Ill.

Brackett, Ross Dudley, Student Engineer, Testing Dept., General Electric Co.; res., 702 Campbell Ave., Schenectady, N. Y.

Burrit, Dwight Fenn, General Superintendent, National Gas Electric Light & Power Co., 1714 Ford Bldg.; res., 1655 Second Ave., Detroit, Mich.

Carleton, Frederick Victor, Electrical Engineer, Westinghouse Elec. & Mfg. Co., Pittsburgh; res., 762 Franklin Ave., Wilkinsburg, Pa.

Clark, Warren Stewart, Designing Electrical Engineer, General Electric Co., Schenectady, N. Y.

Cole, Dale Stevens, Instructor in Electrical Engineering, Cornell University; res., 23 East Ave., Ithaca, N. Y.

Cummings, James A., Jr., Member of firm, J. A. Cummings & Son, 4540 Frankford Ave., Philadelphia, Pa.

Darcey, James Francis, Electrician, Capital Traction Co.; res., 2140 Eye Street, N. W., Washington, D. C.

Davern, Frank C., Arc Lamp Dept., General Electric Co., West Lynn; res., 52 Redington St., Swampscott, Mass.

De Cew, Thomas Leslie, Vice-President and Managing Director, De Cew Co., Ltd., 614 Portage Ave., Winnipeg, Man.

Dobson, George Gordon, Engineer, Western Electric Co., 463 West St., New York City; res., 772 Union St., Brooklyn, N. Y.

Dwight, Herbert Bristol, Electrical Engineer Canadian Westinghouse Co., Ltd.; res., 486 King William St., Hamilton, Ont.

Early, John Wesley, Consulting Engineer, 211 South Downing St., Denver, Colo.

Edwards, Charles Olney, Superintendent, Plains Light & Water Co., Plains, Mont.

Eriksson, Nils Emanuel, Electrical Engineer, Canadian Westinghouse Co.; res., 309 Church St., Toronto, Ont.

Ford, Frederick Howe, Sales Manager, Mechanical Appliance Co., 133 Stewart St.; res., 711 Stowel Ave., Milwaukee, Wis.

French, Richard Clarence, Power Apparatus Sales Engineer, Western Electric Co., 11 Congress St., Lynn, Mass.

Goldschmidt, Elsworth Helbert, Engineering Student, General Electric Co., Lynn, Mass.

Grubmeyer, August Bernard, Industrial Power Dept., Consolidated Gas, Electric Light & Power Co.; res., 17 W. Franklin St., Baltimore, Md.

Haff, Harold L., Electrician, Southern California Edison Co., Long Beach; res., Redondo Beach, Cal.

Harris, Clayton, Salesman, Westinghouse Electric & Mfg. Co., 702 1st National Bank Bldg.; res., 1407 Travis St., Houston, Tex.

Havill, Owen Augustine, Electrical Assistant, Viele, Blackwell & Buck, 49 Wall St., New York City.

Head, Harley Glenn, Sales Engineer, Fort Wayne Electric Works; res., 815 West Creighton Ave., Fort Wayne, Ind.

Hershey, Harry Ellis, Assistant Installer, Automatic Electric Co., Morgan & Van Buren Sts.; res., 1343 Adams St., Chicago, Ill.

Hobcroft, Edward C., Telephone Expert, Western Electric Co., 437 West St.; res., 2871 Webster Ave., New York City.

Jenkins, John Ethbert, Switchboard Operator, Isthmian Canal Commission, Atlantic Division, Gatun, C. Z.

Judson, Lemuel B., Assistant to President, General Electric Co., 30 Church St.; res., 135 West 80th St., New York City.

Krause, Gustave W., Superintendent Electrical Department, Packard Motor Car Co.; res., 258 Josephine Ave., Detroit, Mich.

10964 Hough, J. H., Brooklyn, N. Y.
10965 Johnston, W. R., Wilkinsburg, Pa.
10966 Murphy, W. E., Winnipeg, Man.
10967 Sevin, E. C., Buffalo, N. Y.
10968 Sievers, E. J. J., Hoboken, N. J.
10969 Winchester, L. S., Lowell, Mass.
10970 Taber, F. S., Nowata, Okla.
10971 Howe, H. L., Jr., Rochester, N.Y.
10972 Cureton, J. G., West Allis, Wis.
10973 Ruede, E. M., Winnipeg, Man.
10974 Finkensieper, B. W., Bklyn, N.Y.
10975 Wiggins, S. B., Ann Arbor, Mich.
10976 De Witt, S. C., Toronto, Ont.
10977 Petty, E. W., Chicago, Ill.
10978 Douds, H. J., New York, N. Y.
10979 Edgar, G. E. T., Schenec., N. Y.
10980 Matthews, J. V., Philadelphia, Pa
10981 Heitmann, A. H., Columbus, O.
10982 Kyle, E. L., Philadelphia, Pa.
10983 Waggoner, D. G., Denver, Colo.
10984 Cloake, W. T., Roseburg, Ore.
10985 Baskerville, G. B., Jr., Macon, Miss.
10986 Van Norman, G. S., Detroit, Mich
10987 Downton, P. G., Chicago, Ill.
10988 Lovell, A. H., Ann Arbor, Mich.
10989 Wheelwright, B., Toronto, Ont.
10990 Montgomery, S., Riverside Ill.
10991 Sparling, M. W., Trenton, Ont.
10992 Vogel, L. J., Mansfield, Ohio.
10993 Wendell, C. S., Hackensack, N. J.
10994 Zimmerman, F. L., Detroit, Mich.
10995 Shroyer, J. L., Pittsfield, Mass.
Total, 112.

Students Enrolled December 8, 1911

4728 Pashek, A. L., Mass. Inst. Tech.
4729 Ashinger, H. H., Purdue Univ.
4730 Dunbar, Fred, Purdue Univ.
4731 Hadley, J. L., Purdue Univ.
4732 Inomata, T., Purdue Univ.
4733 Mowry, R. Y., Purdue Univ.
4734 Zimmerman, J. D., Ohio Northern Univ.
4735 Ashley, J. M., Ohio Northern Univ.
4736 Knight, I. W., Brown University.
4737 Viets, R. T., Yale University.
4738 Lannin, E. A., Montana State Coll.
4739 Mackay, W. C.. Mont. State Coll.
4740 Mellen, H. L., Columbia Univ.
4741 Motter, H. W., Lehigh Univ.
4742 Reitman, D. R.. Stevens Inst. Tech.
4743 Haines, W. H., Columbia Univ.
4744 White, R. L., Ohio Northern Univ.
4745 Nipher, E. T., Wash. Univ.
4746 Sewell, R. O., Colo. Agr. St. Coll.
4747 Ramsay, L. M., Purdue Univ.
4748 Smith, E. C., Purdue University.
4749 Weston, G. W., Purdue Univ.
4750 Wymond, P. C., Purdue Univ.
4751 Spring, V. F., Univ. of Michigan.
4752 Norris, L. A., Univ. of Wisconsin.
4753 Hopper, D. C., Univ. of Arkansas.
4754 Muntz, Richard, Univ. of Pitts.
4755 Barry, 3rd, J. L., Mass. Inst. Tech.
4756 Nye, H. B., Cornell University.
4757 Neidich, J. S., Ohio Northern Univ
4758 La Violette, J. W., Wash. St. Coll.
4759 Buzby, P. M., Cornell University.
4760 Carr, W. D., Cornell University.
4761 Cochran, R. L., Cornell Univ.
4762 Depew, Jr. R. H., Cornell Univ.
4763 Gruen, E. C., Cornell Univ.
4764 Russell, S. A., Cornell Univ.
4766 Turner, C. L., Cornell Univ.
4767 Nicholson, F., Cornell Univ.
4768 Rack, E. C., Tex. A. & M. Coll.
4769 Lammers, E. S., Jr., Tex. A. & M. College.
4770 Hunt, N. H., Tex. A. & M. Coll.
4771 Govett, A. V., Tex. A. & M. Coll.
4772 Christen, J. C., Tex. A. & M. Coll.
4773 Ashford, G. W., Tex. A. & M. Coll.
4774 Anderson, M. L., Tex. A. & M. College.
4775 Allen, W. E., Tex. A. & M. Coll.
4776 Boesch, F. J., Tex. A. & M. Coll.
4777 Sowers, C. E., Univ. of Kansas.
4778 Carlisle, G. L., Ohio North. Univ.
4779 Easler, J. T., Stanford Univ.
4780 Robinson, R. L., Stanford Univ.
4781 Pelton, H. E., Stanford Univ.
4782 Mullen, H. A., Stanford Univ.
4783 Wines, H. D., Univ. of Michigan.
4784 Adams, A., Kan. State Agr. Coll.
4785 Stevens, P. S., Washington Univ.
4786 Squire, H. H., Jr., Wash. Univ.
4787 Nebe, W. G., Washington Univ.
4788 Weiss, F. C., Mass. Inst. Tech.
4789 O'Connell, J. F., Rensselaer Poly. Inst.
4790 Scheer, C. H. E., Rensselaer Poly. Inst.
4791 Rock, P. C., Rensselaer Poly. Inst.
4792 Paulsen, R. J. Jr., Univ. of Cin.
4793 Plueddemann, R. O., Univ. of Cin

WINSTON, EARLE G., Electrical Engineer, General Electric Co.; res., 38 Northumberland Road, Pittsfield, Mass.

WOMACK, HENRY ARCHER, General Electric Co., Lynn, Mass.

YOSHIDA, KEIICHI, Chief Electrical Engineer, Musashi Electric Railway Co., Kyobashi-Kaga St., Tokyo, Jap.

Total, 68.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Acting Secretary before January 25, 1912.

10884 Appleton, J. T., Schenectady.
10885 Braconnot, C. P., Rio de Janeiro, Brazil.
10886 Cole, J. M., Washington, D. C.
10887 Crawford, T., Clinton, Iowa.
10888 Darrin, D., New York, N. Y.
10889 Dougall, G. F., Oak Park, Ill.
10890 Erfurth, G. F., Fort Smith, Ark.
10891 Gilman, M. C., Toronto, Ont.
10892 Huey, R. S., Chicago, Ill.
10893 Jones, E. C., Ampere, N. J.
10894 Liversidge, H. P., Philadelphia, Pa.
10895 Mahan, J. S., Chicago, Ill.
10896 Rhodes, S. R., University, N. D.
10897 Williamson, V. B., Jersey City, N. J.
10898 Metcalf, E. S., Buffalo, N. Y.
10899 Cummins, C., Pittsfield, Mass.
10900 Cummins, L., Pittsfield, Mass.
10901 Dellenbaugh, F. S., Jr., New York, N. Y.
10902 Doolittle, H. L., Pasadena, Cal.
10903 Gronen, H. F., Tacoma, Wash.
10904 Gulley, C. L., Toronto, Ont.
10905 Harris, W. C., Philadelphia, Pa.
10906 Hardy, C. H., St. Louis, Mo.
10907 Hirayama, T., Schenectady, N. Y.
10908 Kasson, C. L., Mattapan, Mass.
10909 Pratt, F. C., Schenectady, N. Y.
10910 Stott, James, Vancouver, B. C.
10911 Williamson, G., Ampere, N. J.
10912 Kai, H., Tokyo, Japan.
10913 Amos, W. L., Toronto, Ont.
10914 Baker, H. E., Butte, Mont.
10915 Blake, G. B., St. Louis, Mo.
10916 Chambers, H. C., Vancouver, B.C.
10917 Champreux, A. J., San Francisco.
10918 Hodge, S. E., Portland, Ore.
10919 Holt, C., Fayettville, Ark.
10920 Palmer, R., Schenectady, N. Y.
10921 Stevenson, V. V., San Francisco.
10922 Inouye, T., Moji, Japan.
10923 Whipple, P. S., New York, N. Y.
10924 Stanley, L. L., Pittsfield, Mass.
10925 Sprague, F. D., New York, N. Y.
10926 Smith, W. V., San Francisco, Cal.
10927 Richmond, L. C., Portland, Ore.
10928 Haldeman, H. W., New York, N. Y.
10929 Curtiss, W. L., New York, N. Y.
10930 Corbaley, F. E., Stanford Univ.
10931 Converse, C. M., St. Paul, Minn.
10932 Clark, F. S., Springfield, Ill.
10933 Batchelder, C. C., Schenectady.
10934 Allner, F. A., Baltimore, Md.
10935 Addington, C. B., Paynes Creek, Cal.
10936 Neill, R. D., Ruskin, B. C.
10937 Dods, F. A., Somerville, Mass.
10938 Stude, A. J., Hornell, N. Y.
10939 Ryder, R. W., San Luis Obispo, Cal.
10940 King, J. R., Seattle, Wash.
10941 Thomas, G. M., Berkeley, Cal.
10942 Wopat, J. W., Ann Arbor, Mich.
10943 Pengilly, J. H., Portland, Ore.
10944 Cooke, M. W., Pittsburgh, Pa.
10945 Backus, E. E., El Paso, Texas.
10946 McIndoo, O. W., Syracuse, N. Y.
10947 Harbinson, T. D., Easton, Pa.
10948 Patterson, J., Sydney.
10949 Dow, B. W., Dorchester, Mass.
10950 Olsen, V., Shanghai, China.
10951 Clark, O. A., Schenectady, N. Y.
10952 Jackson, G., Hartwick, N. Y.
10953 Jones, D. W., Terre Haute, Ind.
10954 Markle, D. L., State College, Pa.
10955 Benson, E., Boston, Mass.
10956 Dienner, J. A., Washington, D.C.
10957 Du Bois, W. L., Freehold, N. J.
10958 Lindsley, A. V. S., Syracuse, N.Y.
10959 Nixdorff, S. P., Schenectady, N.Y.
10960 Plumb, M. W., Hamilton, Ont.
10961 Seymour, E. R., Schenectady.
10962 Coors, W. F., Schenectady, N. Y.
10963 Fuller, L. F., Ithaca, N. Y.

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4757 Neidich, J. S., Ohio Northern Univ
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4787 Nebe, W. G., Washington Univ.
4788 Weiss, F. C., Mass. Inst. Tech.
4789 O'Connell, J. F., Rensselaer Poly. Inst.
4790 Scheer, C. H. E., Rensselaer Poly. Inst.
4791 Rock, P. C., Rensselaer Poly. Inst.
4792 Paulsen, R. J. Jr., Univ. of Cin.
4793 Plueddemann, R. O., Univ. of Cin

4794 Corti, J. J., Cornell Univ.
4795 Eastwood, S. K., Cornell Univ.
4796 Lockwood, A. E., Cornell Univ.
4797 Ruckgaber, O. E., Cornell Univ.
4798 Shepard, E. M., Jr., Cornell Univ.
4799 Wetzel, C. H., Cornell Univ.
4800 Semple, J. C., Wash. State Coll.
4801 McElroy, R. B., Wash. State Coll.
4803 Du Vall, C. C., Wash. State Coll.
4804 Barnes, S., Washington Univ.
4805 Lassaff, B., Ohio Northern Univ.
4806 Steele, H. S., Bucknell Univ.
4807 Bressler, J. W., Bucknell Univ.
4808 Shaffer, H. A., Bucknell Univ.
4809 Fairchild, E. E., Bucknell Univ.
4810 Stetler, A. M., Bucknell Univ.
4811 Hooker, C. B., Bucknell Univ.
4812 Richards, E. M., Bucknell Univ.
4813 Brewster, W. E., Univ. of Minn.
4814 Wilcox, L. W., Univ. of Minn.
4815 Purves, L. E., Univ. of Minn.
4816 Hitchcock, H. W., Cornell Univ.
4817 Phillips, C. E., Bucknell Univ.
4818 Bliem, H. M., Lafayette College.
4819 Hamilton, R. F., Colorado College.
4820 Love, N. R., Colorado College.
4821 Bruhn, H., Ohio Northern Univ.
4822 Livingston, J. K., Univ. of Wisc.
4823 Kempf, F. J., Purdue University.
4825 Freygang, W. H., Stevens Inst. Tech.
4826 Codding, H. W., Mass. Inst. Tech.
4827 Morgan, F., Univ. of Michigan.
4828 Rooke, R. L., Bucknell Univ.
4829 Hoot, D. W., Iowa State College.
4830 Wahaven, J. W., Iowa State Coll.
4831 Mott, C. H., Iowa State College.
4832 Martin, E. E., Iowa State College.
4833 Summers, W. G., Iowa State Coll.
4834 Kilby, D. H., Iowa State College.
4835 Walton, J. N., Iowa State College.
4836 House, W. M., Iowa State Coll.
4837 Elder, P. M., Armour Inst. Tech.
4838 Sells, H. J., Ohio Northern Univ.
4839 Braunig, H. E., Tex. A. & M. Coll.

Total, 110.

Recommended for Transfer

The following Associates were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on December 5, 1911. Any objection to the transfer of these Associates should be filed at once with the Secretary:

ALBERT M. ALLEN, Consulting Engineer Cleveland, Ohio.

CHARLES W. PENDELL, Engineer, Contract Department, North Shore Electric Company, Chicago, Ill.

ARTHUR L. MUDGE, Electrical Engineer in Charge of Construction, Smith, Kerry and Chace, Toronto, Ont.

WILLIAM C. BAUER, Head of Electrical Engineering Department, Northwestern University, Evanston, Ill.

WALTER E. HOLLAND, Chief Electrical Engineer, Edison Storage Battery Company, Orange, N. J.

SAMUEL INSULL, President, Commonwealth Edison Company, Chicago, Ill.

Public Control of Public Utilities*

BY PROFESSOR GEORGE A. DAMON

For the last three years I have been connected more or less with the movement of public control of public utilities; for two years in New York, our firm being consulting engineers for the Public Service Commission of the First District; for eight months in Pittsburgh, studying the transportation problems there, and since last January I have been here, almost constantly connected with the question of the control of public utilities. I am often asked where the movement started; and where it is going to end. There is no question about its having been started. The people here a few years ago found out that they had a right to control—they were a long time in finding it out—and there is no question about their right to control. I have heard it stated that the state has a right to everything; to your property and to my property if it is necessary for the good of the state. But it has not the right to take your property without compensation, and in exercising this right of public control we are still very young and have a great deal to learn. My idea as to how it will develop is this; first, it is to be public control; then it is to be public partnership; and then it is to be public ownership, but not necessarily public operation. Let me give you some of the reasons for this belief. Public control, of which we know so little at the present time, and which as yet is not exercised at all in a scientific manner, especially in this state, must rest fundamentally upon the following propositions: First, it should secure for the people adequate service. Now note, I do not put the regulation of rates first. To the popular mind right of control means the regulation of rates, and the regulation of rates downward. I believe in the regulation of rates and I believe in the regulation of rates downward. It is the natural tendency and we should work for it. It is the thing the engineers of this country are going to bring about, but it is not the first essential. It is the very last one. Public control, to my mind, means securing to the people adequate service. We need better service; we need better street car service; better light service; better telephone service. There is no public utility that is adequate. So the first essential of public control is a technical problem of how to secure adequate service. The second fundamental is to protect the investment. There has been a great deal of money invested in these public utilities; there has been a great deal of time and energy put in them; we cannot confiscate that investment; that time, ability and energy; it should be rewarded with something more than simple interest rates such as we can get on a farm mortgage. We must find some way, then, to protect the investment. There must be a fair return on a fair investment. Now that is another technical question that the technical man must solve, and we must have the opportunity to solve it; it must be given to us to solve. What is the investment and how are we going to determine what it is? That involves all of the problems of appraisal and valuation; and question of determining depreciation; the question of return, and what a fair return is upon a fair investment. These are all technical problems. The third essential fundamental to my mind is to provide some adequate form of renewal. If our service is to be adequate; if our investment is to be protected, we must have some automatic form for keeping the plant up to date and up to the highest efficiency, so we must study the question of depreciation and the requirements of the renewal fund; that is the third essential. The fourth is the question of improvements and extensions. Some people have the idea that a public utility becomes finished after the investment is made, and that that is all there is to it. Even the bonding people begin to retire their bonds after a certain date as if they could go about so far and then get out of the business. Take the question of transportation. It is a utility that calls, as all other utilities do, for a constant source of new capital; we must be constantly extending the system. From my study of the transportation systems of the entire country I found this to be true; that the riding habit increases as the square of the population; that means that when the population doubles, the income per capita doubles, and if the income per capita doubles and the population doubles, your total income goes up four times; in other words, when the population doubles, you count upon the total income increasing four times. Now every dollar of increased earnings in transportation means about four dollars additional investment. Take it right in this town. Today the local railways are taking in at about the rate of five million dollars a year. By the time the population of Los Angeles doubles inside of the present city limits the local transportation system may be taking in, if the increase is in the same proportion as the other cities of the United States, twenty million dollars a year, and our investment that we must follow that up with will increase four times. So that the fourth essential is an unlimited supply of new capital for improvements and extensions. Now we cannot get that unlimited supply of capital at reasonable rates unless we protect the present investment. If you attack the present investment and scare away capital, how are you going to make the extensions and provide for your credit? The answer is to so thoroughly protect the investment that instead of going to the brokers in Wall Street and giving them discounts to secure us money—possibly selling bonds at eighty or ninety and paying five per cent interest, we have such protected investment that we will tap the till at four or five per cent. There is an unlimited supply of money that is available for investment, without security, at four or five per cent if it can be placed in a protected investment. The next essential that I shall touch upon is very seldom spoken of, and that is the requirement to advertise part of the investment. We recognize in making appraisals that there is something more than the physical value or the cost to produce the plant; we recognize what we are pleased to term development expenses; some people call them "intangible values". They consist, for instance, of the discounts on the securities that have been passed out; of the profits of promotion, because these promoters should have some profits; of the cost of consolidation, because it costs money to get together the several systems that go to make us a complete public utility; they consist of, perhaps, a few engineering mistakes in the past that are almost unavoidable in the developing of the property, and of a number of investments that do not show upon the surface but possibly may amount to all the way from twenty to thirty per cent of the cost of producing the plant but because they are "intangible", because you cannot see them, because you have to theorize about them, it would be better if the capital represented by those developing expenses is wiped out. So I maintain that out of the first real earnings of the plant money should be taken to retire the investment in those development or intangible values, and there should be a fund created for that purpose. This is a point that is very often overlooked.

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*Abstract of an address by Professor George A. Damon, of Throop Polytechnic Institute, Pasadena, at a meeting of the Los Angeles Section of the A. I. E. E., held on October 17, 1911.

The next essential is to eliminate competition. We thought that the proper method of regulating public utilities was by means of competition, and if we had a telephone company that was not giving us good service we gave a franchise to another telephone company and sought to regulate the question that way; or in the case of a lighting company that did not give us good service we gave perhaps another franchise to a hostile plant. Well, what is the result? We have a duplicate investment; two dollars doing what only one dollar should do; a duplicate management; we have inefficiency all the way down the line. The competition cuts the rates and neither company can give us good service, and I think we are prepared to say that competition is not the answer. So that one of the essentials of the future development of public utilities is to eliminate competition. Public utility work is a natural monopoly; it should be encouraged as a monopoly, but a regulated monopoly, a protected monopoly, though still a monopoly. If we allowed this monopoly under established rights to regulate, how are we going to control it? Fix the rates so that they are sufficient to take care of these fundamentals that I have mentioned. Make the rates high enough to refuse to reduce them until such time that the income will take care of these fundamental essentials; until we have a depreciation fund to take care of our renewals; until we can be sure that we can take care of our expenses; until we can pay a proper return on the investment; until we have money in the surplus fund to advertise some of the capital, and then let us retire some of it. There should be a surplus fund created with every public utility, but that surplus fund should not belong to the company. To my mind here is where scientific regulation can do its best work. Let the control of the fund be in the hands of the technical men who understand business and what can he do? Why, he has a fund then that he can do anything with. If he wishes to renew some part of the property or replace some inefficient part with something that is more efficient so as to cut down the cost of operation, this fund will be available for that purpose. If he wishes to extend some of the plant into parts of the city where it will be a non-paying road for a little time and yet build up that section, that fund is there for that purpose. If he wishes to advertise some of the capital so that the fixed charges will be reduced, that fund will be there for that purpose. It will give a stability to the whole proposition that will guarantee a return on the investment, and capital will be glad to come in and furnish the necessary money. Finally, when the fund gets sufficient to do all these things, and more, then is the time to cut your rates. Hence the reduction of the rates is the last thing. While the whole program tends towards the regulation of the rates it does not put the regulation of rates downward as the first essential. Now how are we going to work to bring that about? Why, don't you see, if we get control of this surplus fund of these corporations and we take the corporations in hand and make them stable by insuring a return on their investment and protecting that, that we are thus in partnership with the utility company at once? That is public partnership. This is not a theory, it has been worked out in actual practice. We have practically this same arrangement in Chicago, In working out the transportation problem there, a contract ordinance was entered into between all of the railway companies and the city in which all of the railway companies were combined so as to have one system or monopoly. The companies were given five per cent return on their actual investment and the investment was protected. The Chicago railroad companies can get all the money they want at five per cent, an unlimited supply, on the primary security of the company. The fund was then divided fifty five per cent to the city and forty-five per cent to the company, and the company was required by ordinance to maintain the property and have a sufficient renewal fund; and in making the arrangement these intangible values were given a certain value, and a great many of them were advertised at that time. Today the City of Chicago and the railway companies are in partnership, and the City of Chicago takes fifty-five per cent of the net and they put that fund in a bank. That fund has not been touched and it is available today to either build subways with, to extend the service into non-paying districts, to reduce the fare if they wish to, or to buy out the company. So public partnership will actually end in public ownership; because after we have learned the business and have treated the man who has taught us the business right because of our having been in partnership with him, we will finally say to Mr. Public Utility Man, and particularly the promoter and the capitalist, " Now don't you think you would like to take your money out of this enterprise and go into some other business where there is a possibility of making more money, and let us run this thing on a five per cent basis?"

But I want to tell you there is a danger. Every operator of every utility recognizes that today. He will say, what is going to become of me? I don't want to work for the public; I don't want to work for the city; I don't want to work for the government; I don't want to play politics to keep my job; what is to become of me? I am going to get out of the business if it is to come to that. And to my mind if it does end in public ownership and operation of these utilities there will be that danger, and I see only one way of overcoming it, and that is after we get public ownership we eliminate public operation and turn over the operation of these utilities to operating companies organized on very similar lines to the operating companies of our present utilities, which will be without any necessity of raising capital or without any necessity of financing, or getting franchises, or manipulating, or going into politics. I have talked this thing over with some pretty big utility men in this country and I think I can see the day when there will be some such operating companies, known by the name of the man at the head of them, composed of prominent financiers with an organization working on a bonus proposition. We worked out a proposition of this kind on the New York subways, and it worked out all right. It has been looked into by some prominent operating men who quite agree upon its feasibility.

Those are the technical problems that you have to face, and I do not see how you are going to get away from it. If you do not work for some public service company, you at least use the service.

How are we going to deal with the question out here? The first move we have to make is to be found right in politics. Last week we voted to extend the duties of a State Railroad Commission so that it would have the power of regulation of most of the public utilities in this state. The Railway Commission of Wisconsin to my mind is an ideal one. Although, as I say, I was with the Public Service Commission of New York for two years I still regard the Wisconsin Commission as the premier organization. Why? Because they organized at once and turned over all of their technical problems to an engineering organization. They went to the state university and turned over the engineering department of that Wisconsin Commission to the professors of that university, who at once organized for the purpose. The commission then began to work up a fabric of decisions. every one of which was based upon reports of these engineers. Four volumes are now in print, and it will be instructive to notice how the commission took the little cases first and gradually built up the splendid fabric of decisions which they now have. The result is that in the State of Wisconsin the public utility business is in a state of absolute balance. It is protected, and as I understand it in no single court case has the decision of the commission been questioned.

California has that opportunity. Whether we have a state commission that will be wise enough to organize in that way I don't know, but they have this Wisconsin precedent before them for their guidance. Personally I should be glad to see them take as their technical assistants the professors and technical organization of our state university. I should be glad to see the state commission so efficient in its work, so careful in its judgment and so commanding the confidence of every citizen that Los Angeles itself would feel impelled to turn over its problems of regulation to a commission which would be entirely free from any local political influence.

Annual Tables of Constants and Numerical Data

The first volume of the *Annual Tables of Constants and Numerical Data, Chemical, Physical and Technological,* compiled and published by an International Commission appointed by the Seventh International Congress of Applied Chemistry (see *Science*, August 4, 1911, p. 158) is now open to subscription. Subscription blanks, the terms of subscription and descriptive leaflets may be obtained from any one of the three American commissioners: Dr. G. N. Lewis, The Massachusetts Institute of Technology, Boston, Mass., Professor G. F. Hull, Dartmouth College, Hanover, N. H., and Professor

J. Stieglitz, the University of Chicago, Chicago, Ill. After January 15, 1912, the price of the volume is likely to be increased.

Fundamentals of Electrostatics

At the regular monthly meeting of the Schenectady Section held on December 5, the members were addressed by Dr. W. S. Franklin, of Lehigh University, on "Fundamentals of Electrostatics." The address was illustrated by experiments, simple mathematical equations thrown on a screen by a stereopticon, and by means of mechanical analogies.

Dr. Franklin first explained the storage of electrostatic energy on conductors by machines such as the Toepler-Holtz and Wimshurst. The principle involved was illustrated by a simple machine consisting of two cups placed near to but well insulated from each other and provided with a strip of pith on each side, and two free metal balls similarly insulated. The machine was operated by bringing the metal balls into contact over the cups, then separating and placing them inside of the cups, then removing and bringing them into contact again. This cycle was repeated about 50 times after which the pith strips were then seen to slowly rise, showing that the cups had been charged with electrostatic energy. Dr. Franklin compared this machine, which he called an "electric doubler", to the following mechanical analogies: First. A winch such as is used on shipboard for winding up cables. Second. A pack of cards with a number of rubber bands placed about them. In both cases the continued addition of small stresses finally results in crushing the material to which the pressure is applied.

The breakdown of a medium of low inductivity under electrostatic stress when another medium of high inductivity is introduced in the electrostatic field with it was next illustrated. Two metal plates in air were connected to a high-voltage transformer and charged to a potential just not sufficient to break down the air. A sheet of glass was then introduced between the plates and the air remaining between immediately broke down. It was shown that this was due to the difference in inductivity between the two mediums interposed between the two plates. This phenomenon was illustrated by a mechanical analogy in which cylinders of two materials such as rubber and steel are placed parallel between the parallel plates of a compression machine. When pressure is brought to bear upon these two materials, they are both compressed through an equal distance, but the strain in each is different, depending principally upon their coefficient of elasticity. Similarly, the inductivity is comparable to the coefficient of elasticity, and the material with the higher inductivity broke down less easily than that with the lower inductivity under the same electrical stress.

The force exerted by an electrostatic field was next illustrated. A sheet of glass balanced on knife edges was placed between two metal plates. When the plates were charged by an influence machine, the glass sheet was drawn into the electrostatic field just as a piece of iron would be drawn into a magnetic field. This principle was then extended to show the method of exploring an electrostatic field by means of a strip of insulating material freely hung on an insulating thread. Dr. Franklin used for this a tooth pick hung on a silk thread, or a glass rod of small diameter, similarly hung. When these were placed in the electrostatic field, it was found that they placed themselves in such a position as to carry a maximum number of lines of force. In other words, they acted precisely in the same manner as a steel needle would act when under the influence of an electromagnetic field.

Dr. Franklin called particular attention by these two experiments to the close similarity between electrostatic and electro-magnetic phenomena and recommended the study of the two in conjunction with simple mathematical equations and mechanical analogies. He stated it was the custom at present to consider two different systems of units when dealing with electrostatic and electromagnetic conditions, and that these two systems although they approach each other, never join, always leaving a gap. This he thought very undesirable.

Attention was called to the erroneous idea about electric machines being electric generators. It was pointed out that they are comparable to a pulley around which a leather belt is wound. According to the phraseology applied to electric machines, we may call the pulley when it revolves, a " leather generator " while in reality it is only a means of transmitting power, the same leather belt always running around the same pulley. Similarly, a generator of electricity is a producer of electrical energy, and as the pulley serves to tie together two machines and transmit power between them, so the electrical generator serves to transmit power to machines which utilize it.

The subject was briefly discussed by Mr. W. S. Andrews and Dr. Charles P. Steinmetz.

Dr. Steinmetz agreed with Dr. Franklin concerning the parallel treatment of electrostatic and electromagnetic phenomena and stated he believed that the electrostatic units were of sufficient importance to receive names and have symbols assigned to them just as have been assigned to the electromagnetic units.

Utilization of Waste Steam at the Milwaukee Refuse Incinerator

At the November meeting of the Milwaukee Section of the American Institute of Electrical Engineers, held in coöperation with the Engineers Society of Milwaukee, Mr. J. A. Neseroff, city engineer of Milwaukee, presented a paper on " The Utilization of Waste Steam at the Refuse Incinerator and the Electrification of Two River Flushing Stations."

The City of Milwaukee now operates a refuse incinerator in which all classes of refuse are burned in special furnaces under special boilers. At the present time the steam is blown off except a very small portion used to run the plant. Tests made showed that the steam available varied widely, depending on the grade of refuse, being lowest when green garbage was fed to the furnaces. Further tests showed that by adding a very small amount of coke dust to the charges of green garbage, enough steam could be raised to produce 600 kw. at all times, although at some times nearly three times this amount would be available.

Since it is undesirable to make a large investment in machinery at this time, it has been decided to install one 600 kw. steam turbine and proper auxiliary apparatus in a new engine house adjoining the incinerator. The nature of the steam supply and the absence of spare units made it inadvisable to utilize this power supply for service requiring great reliability, and street lighting would not be economical by reason of the absence of any day load. The city, however, now operates by steam two pumping plants taking water from the lake and forcing it through tunnels into the rivers running through the city, for the purpose of flushing them to carry off sewage. One plant is only two years old, with a capacity of about 200 h.p., while the other is 24 years old, with a capacity of about 250 h.p. Both run practically continuously but a few hours shut-down would not be disastrous. This load therefore seems ideal as an outlet for the power available at the refuse incinerator.

The plans contemplate 6600-volt, three-phase underground transmission to induction motors in the two pumping stations, about two miles in each case, and the removal of the present steam engines. The motors will be geared to the present shafts.

Figures were given of the cost of operation of the present steam pumping stations and it was shown that by an investment estimated at $80,000, a saving of approximately $28,000 a year could be made. This did not make any allowance for interest or depreciation on the new investment, nor did it include any value for the steam that will be used. As the steam is now a waste property of the city it is merely a matter of bookkeeping whether the economy is shown in the pumping plant by using waste steam, or whether the steam is charged against the pumping stations, and the economy shown in the operation of the incinerator.

The discussion which followed the reading of the paper was general, and involved criticisms of the present operation of the steam plants and suggestions that other more profitable markets be selected for the use of waste steam, but no practical suggestions were made that appeared better than the plan already adopted.

This meeting was the second of the year dealing with the engineering side of local civic problems and the discussion showed the active interest that engineers may take in municipal problems, when the information is obtained from reliable sources, and not subjected to political news distortion.

Analysis of Rubber Compounds

It is a well recognized fact that the art of analyzing rubber compounds has not reached the state of perfection which the commercial importance of rubber products seems to warrant. Various chemists have developed methods of analysis possessing more or less merit, but at the present time these methods cannot be relied upon to give concordant results. Users of rubber insulated wire are particularly interested in the analysis of rubber compounds owing to the recent practice of inserting chemical clauses into specifications. The manufacturers are equally interested because in the present state of the art, they are likely to have insulation refused by their customers, not because it is defective, but because some unforeseen method of chemical analysis indicates that the specifications have not been complied with. Chemists are interested not only in the scientific aspects of the problem, but also in its commercial aspects, because the chemical specification for rubber, with all it implies in its relation to chemists, will drop out of use unless the chemists are able to stand back of it with an analysis that cannot be controverted. Realizing these conditions, Mr. E. B. Katte, Chief Engineer of Electric Traction of the New York Central Railroad, invited a number of prominent manufacturers, consumers and chemists, to a conference at which the subject of rubber specifications could be discussed and steps taken to secure the desired uniformity in rubber analysis.

The conference was held on December 7 at 335 Madison Ave., the attendance including representatives of the U. S. Army, the New York Central Railroad, The Pennsylvania Railroad, The General Electric Co., The Standard Underground Cable Co., the Simplex Electrical Co., The Hazard Manufacturing Co., The American Chemical Society, and several chemists who have made a specialty of rubber analysis. Major Samuel Reber was elected chairman and after a discussion of the various aspects of the problem, the following committee was nominated to determine a standard procedure in the analysis of rubber compounds:

Mr. H. B. Rodman, Chemist, Pennsylvania R.R., Altoona, Pa.

Mr. C. R. Boggs, Chemist, Simplex Electrical Co., Cambridge, Mass.

Mr. W. B. Gieser, Chemist, New York Central Railroad, Albany, N. Y.

Mr. P. Poetschke, Chemist, The Lederle Laboratories, 39 West 38th Street, New York.

Mr. James P. Millwood, Consulting Chemist, 246 Willoughby Ave., Brooklyn, N. Y.

Mr. Wallace Clark, Head of the Wire & Cable Dept., of the General Electric Co., Schenectady, N. Y.

Mr. W. A. Del Mar, Assistant Engineer, New York Central R.R., 335 Madison Ave., New York.

The work of the committee will be largely in the nature of laboratory tests and comparison of results by correspondence and periodic meetings. Suggestions and communications will be received by the Secretary, Mr. W. A. Del Mar.

Past Section Meetings

BALTIMORE

The regular monthly meeting of the Baltimore Section was held on Friday evening, November 24, in the physical laboratory of the Johns Hopkins University, Baltimore. Professor R. W. Wood gave a lecture on "Photography with Invisible Rays", which was copiously illustrated by lantern slides and experiments. The Baltimore Engineers Club had been invited to attend, and about 60 members of the two organizations were present.

CLEVELAND

The Cleveland Section held its regular monthly meeting in the library of the Chamber of Commerce on Monday evening, November 20. Owing to illness in his family, Mr. W. J. Hagenah, of Chicago, who was scheduled to address the members on "Public Utilities and Public Utility Commissions", was not able to be present. Mr. Ralph W. Pope, Honorary Secretary of the Institute, was a guest at this meeting, and discussed a number of matters relating to the welfare of the Section.

FORT WAYNE

The Fort Wayne Section gave a smoker at the Fort Wayne Commercial Club on November 16. The principal feature of the evening was an address by Mr. Thomas W. Behan upon the subject "Development of the Magnetite Arc Lamp and Luminous Arcs." A social hour followed during which refreshments were served.

ITHACA

The Ithaca Section resumed its activities for the season of 1911–1912 at an informal gathering on October 6. The chief function of this first meeting was to get acquainted with prospective members and to acquaint them with the work of the Institute in general, and the Ithaca Section in particular, to point out the advantages to be obtained by young engineers becoming connected with the Institute as enrolled students, and later as Associates and Members.

Professor H. H. Norris gave a talk on "Heavy Electric Traction", in which he reviewed the extent to which steam railroads in this country have electrified, including an account of electrification work now under construction.

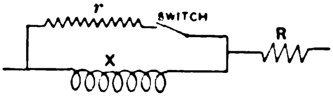
Secretary George S. Macomber gave a brief account of a motor-cycle trip made by him from Ithaca to Chicago and return.

Ninety members and guests were present.

The Section held its next meeting on November 1. Mr. Ralph W. Pope, Honorary Secretary of the Institute, was the guest and speaker at this meeting. Mr. Pope gave a brief review of his observations of the rise and development of the electrical art from the time when he became the Secretary of the Institute, including many personal reminiscences. Seventy-five students attended the meeting.

A meeting held on November 15 was devoted to the subject of electric power transmission. The following papers were reviewed: "Transmission System from the Operating Standpoint", by R. J. C. Wood, (April, 1911 PROCEEDINGS); "Transmission System of the Great Western Power Company", by J. P. Jollyman, "Transmission System of the Southern Power Company", by W. S. Lee, "Transmission System of the Great Falls Power Company", by M. Hibgen, (July, 1911, PROCEEDINGS). Much interest was added to the discussion by the remarks of a number of members present who had inspected one or more of the systems described.

On November 27 the members were addressed by Mr. J. G. Pertsch, who presented an original paper entitled "Some Impedance Paradoxes." The paper considered two cases of electrical impedance problems. The first consists of impedance as shown in the accompanying cut, in which *R* is a resistance in series with a parallel circuit composed of a resistance *r*, and a reactance *X*. A switch in series with *r* enables that branch to be opened or closed. Under usual conditions if the switch is closed the total impedance will be reduced, but Mr. Pertsch showed that under certain conditions closing the switch will produce no effect, and again, under conditions representing different ratios of *R*, *r* and *X*, closing the switch will actually increase the total impedance. The results were shown experimentally, analytically, and by graphics.



The second paradox is of the same nature, but deals with resistance only.

"Polycyclic Currents" was the subject of a talk by Mr. F. Bedell at the conclusion of Mr. Pertsch's paper. It was in reality an extension of the case of ordinary alternating current representation by vectors in a plane to the case for currents of two different frequencies on the same wires in which the representation by vectors required vectors in three dimensions, *i.e.*, space vectors, and for the cases where more than two different frequencies are employed it is impossible to draw the vector diagram, for it requires a space representation of more than three dimensions, which is impossible of representation graphically.

LOS ANGELES

The regular monthly meeting of the Los Angeles Section was held on October 21. Sixty-six members and visitors were present. Professor Harris J. Ryan, of Stanford University, presented a paper on "Polarity in Polyphase Circuits." The paper was discussed by Professor R. W. Sorensen, Messrs. E. F. Scattergood, J. A. Lighthipe, Budd Frankenfeld, and O. H. Ensign. Professor Ryan's paper was published in the *Journal of Electricity, Power and Gas*, issue of November 11, 1911.

LYNN, MASS.

The Lynn Section held its fourth meeting at Odd Fellows Hall, West Lynn, on November 9. There was an attendance of 317 members and visitors, which included a large number of students. The speaker of the evening was Professor Elihu Thomson, who gave a lecture on the subject "Some Electromagnetic Analogies", which was illustrated by apparatus and experiments.

MADISON, WIS.

The first meeting of the Madison Section for the year 1911–1912 was held on Tuesday evening, November 21, in the lecture room of the City Library. Twenty-two members were present. Mr. J. N. Cadby gave a report of the conference of Section delegates and Institute officers at the Chicago Convention of the Institute last June, which he attended as the representative of the Madison Section.

The paper of the evening, on the subject "Some Problems in Street Illumination", was presented by Mr. E. N. Strait, expert for the Railroad Commission of Wisconsin. The paper dealt with the history of street illumination and the difficulties experienced in determining what constitutes efficient illumination. Mr. Strait emphasized the necessity of making all contracts for street lighting very specific in respect to what illumination is to be furnished, and cited several instances where trouble had arisen due to the specification of "2,000 candle-power lamps."

MEXICO

The annual meeting of the Mexico Section was held in the Y. M. C. A. Building, City of Mexico, on November

10, with Acting Secretary Hale presiding. About 30 members and guests were present. The following officers were elected for the year ending July 31, 1912: Chairman, W. H. Fiske, chief engineer of the Mexico Tramways and Mexican Light and Power Company; secretary, H. S. Foley, superintendent of distribution, Mexican Light and Power Company. The chairman was authorized to appoint an executive committee of three members. Mr. Hale presented a paper describing a recently completed underground cable installation in Puebla, Mexico. Mr. P. M. Bennett gave a description of the laying of telephone and electric light and power cables in the same city. Both papers were illustrated by photographs of the work and samples of the cables.

MILWAUKEE

The Milwaukee Section held its regular meeting in the Plankington House, Milwaukee, on November 15, in coöperation with the Engineers Society of Milwaukee. Mr. J. A. Neseroff, city engineer of Milwaukee, gave a paper on "The Utilization of Waste Steam at the Refuse Incinerator and the Electrification of Two Rivers Flushing Stations", an abstract of which will be found elsewhere in this issue. Seventy-seven members of the two societies attended the meeting.

MINNESOTA

The regular monthly meeting of the Minnesota Section was held in St. Paul Hotel, Minneapolis, on November 17. A paper on "The General Principles Involved in Rate Making for Public Utilities" was presented by Professor William D. Marks, which was discussed by Messrs. Edward P. Burch, Charles L. Pillsbury, E. T. Street, and F. R. Cutcheon. Thirty-two members were present.

PHILADELPHIA

The Philadelphia Section held its regular meeting on November 14, in the Philadelphia Electric Company's building. Eighty-nine members were present. Dr. George A. Hoadley, official delegate of the Philadelphia Section to the Institute convention last June, gave a report of the convention, including the Sections conference.

A paper on "Alternating and Direct Current Motors in Industrial Service" was presented by Mr. W. F. James. The paper was discussed by Messrs. Snook, Hornor, James, Tracy, Neary, Hoadley, Chilton and Hering.

The next regular meeting was held in the Philadelphia Electric Company's building on December 11, with an attendance of 49 members. A paper entitled "A Resume—Generator and Line Reactance and the Oil Switch" was presented by Mr. A. R. Cheyney, and discussed by Messrs. Snook, Cheyney, Hoadley, Green, Bonine, Livesy, Hering, Kershner, Penrose, and Tracy.

PORTLAND, ORE.

The Portland Section held its regular meeting in the assembly hall of the Electric Building, Portland, on Tuesday evening, November 21, 1911. A special committee recommended that a monthly luncheon or dinner should be given the members of the Section, in order to promote more interest in meetings, and to enable members to become better acquainted. The executive committee reported that it was arranging to obtain papers for the proposed Pacific Coast meeting of the A. I. E. E. in Portland next April.

Professor R. H. Dearborn, of the University of Oregon, presented a paper on "Physical Valuations of Electric Properties in Oregon." Professor Dearborn expressed his pleasure at being able to present a paper before the Portland Section and his regret that he had been unable to attend more meetings in the past. The paper gave the results of his investigations made for the State Tax Commission in order to arrive at some consistent and reliable valuations of the different electric properties operating within the state. Professor Dearborn explained that due to the short time at his disposal no very thorough study could be made of each property.

SCHENECTADY

The regular monthly meeting of the Schenectady Section was held in Red Men's Hall on December 5. About 285 members were present. A paper was presented by Dr. W. S. Franklin, of Lehigh University, on "Fundamentals of Electrostatics", an abstract of which will be found printed in this issue.

SEATTLE

The Seattle Section held its monthly meeting in the Electric Building, Seattle, on November 18. A paper on "Water Power Development" was read by Mr. E. G. Allen. The paper dealt with the White River development of the Pacific Coast Power Company, describing the project from the beginning of the construction work to its final completion. Fifty-seven members were present.

TOLEDO

Professor Guthe, of the University of Michigan, addressed the members of the Toledo Section at its regular monthly meeting held on November 28. Mr. Ralph W. Pope, Honorary Secretary of the Institute, was also a guest at this meeting. Professor Guthe spoke on the subject, "Electrons", discussing the various electrical theories which finally led to the adoption of the electron theory. A discussion followed by Messrs Pope, Kirk, Gilmartin, Nickels, Jewett, Grah, M. Neuber, and others. At the close of the discussion Mr. Pope gave a talk on Institute affairs.

TORONTO

The Toronto Section held its regular monthly meeting on Friday, November 24, at the Engineers' Club, Toronto. The meeting was preceded by an informal dinner at which 35 members were present. One hundred and fifteen members attended the meeting. The speaker was Mr. J. W. Fraser, assistant chief engineer of the Southern Power Company. Mr. Fraser read a paper on "The 50,000 and 110,000-Volt Transmission System of the Southern Power Company", which he illustrated with lantern slides. The paper was discussed by Professor Rosebrugh, P. W. Sothman, A. L. Mudge, J. A. Johnson, H. S. Brown, and others.

WASHINGTON, D. C.

The December meeting of the Washington Section was held in the Telephone Building on the 12th instant. Mr. Paul M. Lincoln, of the Westinghouse Electric and Manufacturing Company, and Chairman of the Sections Committee of the Institute, gave a talk on the "Water and Electric Power Development at Niagara Falls", the lecture being illustrated with a series of lantern slides. Although the speaker apologized for the triteness of his subject, it proved exceedingly interesting to the large audience present. Touching upon the mooted question of whether the diversion of water for power development purposes has affected or, when the total amount authorized by the present treaty, 56,000 cubic feet per second, has been diverted, it will affect the scenic grandeur of the cataract, Mr. Lincoln allayed the fears of some of those present by the statement that a variation which obtains of approximately 50 per cent in the natural flow of the Niagara River does not affect the appearance of the cataract to the average observer. This large variation in the discharge from Lake Erie is independent of the season of the year and is caused by the wind upon Lake Erie piling up the water in either the East or West end of the lake, depending upon its direction, the extreme variation in the height of the water at Buffalo due to this cause being 14 feet. As the mean flow of the Niagara River is something like 225,000 cubic feet per second it appears that even when all of the 56,000 cubic feet per second which has been authorized, is being diverted through the various tunnels and canals, the scenic beauty of the Falls will not have been impaired thereby, although the construction of power houses, factories, etc., in and adjacent to the Niagara Gorge, of course produces a disfiguring effect. Mr. Lincoln's paper was discussed by Mr. John H. Finney of Washington, D. C., who also made some remarks on the subject of conservation, speaking in support of the general conservation movement, and warmly endorsing the plea for a liberal governmental policy toward conservation. There was a further discussion of the subjects of water power and conservation by Messrs. Earl Wheeler, P. M. Lincoln, H. C. Eddy and others.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The University of Arkansas Branch held its regular meeting on November 27. Mr. L. R. Hulse read an abstract of the paper by Mr. Gus A. Maier, on "Methods of Varying the Speed of Alternating Current Motors", appearing in the December PROCEEDINGS. Mr. A. J. Collins reviewed current events in the electrical field. Dr. C. H. Brough gave a talk on "Conservation of our Natural Resources."

The Branch held its next meeting on December 5. A paper on the cost of arc lighting was read by Mr. N. R. Laughinghouse. Mr. Coutrell gave a review of current events. Professor Greever gave a talk on the value of reading magazines, and classified the kind of information to be found in the various publications under discussion.

ARMOUR INSTITUTE OF TECHNOLOGY, CHICAGO

The Armour Institute Branch held its regular meeting on November 8. Mr. H. P. Langstaff gave an illustrated talk on "Power Development by the Winnipeg Electric Railway Company." Mr. Langstaff first described the location of the generating plant, showing how the natural advantages of the site had been utilized. He next showed the arrangement of the interior of the generating station and described the system of operation. A complete wiring diagram of the station was exhibited, and views were shown of the transmission line and sub-stations.

The Branch held a joint meeting with the local Branch of the A. S. M. E. on November 21. The speaker of the evening, Professor G. M. Wilcox, gave a lecture on "The Practical Application of the Gyroscope." Professor Wilcox first explained the principles of the gyroscope, showing that its actions are the result of simple mechanical laws. The use of a gyroscope to reduce the rolling of a ship was demonstrated by attaching the gyroscope to a pendulum. It was also shown by a small model, that the rotating flywheel of the engine on an aeroplane, or the propeller, if only one is used, may cause the machine to tilt about a horizontal axis is a quick turn is made about a vertical axis. The lecture closed with an explanation of the principal features of the Brennan Mono-Rail car, of which a working model was exhibited.

A special meeting of the Branch was held on November 23 in order to welcome Mr. Ralph W. Pope, Honorary Secretary of the Institute, who was visiting some of the Sections and Branches in the Central West. Mr. Pope addressed the students on "The Reliability and Responsibility of the Engineer."

BUCKNELL UNIVERSITY, LEWISBURG, PA

The Bucknell University Branch held its second meeting on December 13, in the engineering lecture room of the university. Mr. H. S. Sweet read Mr. E. F. Alexanderson's paper on "Magnetic Properties of Iron at Frequencies up to 200,000 Cycles", which was published in the December PROCEEDINGS.

UNIVERSITY OF COLORADO

The regular meeting of this Branch was held on November 15. Fifty-four members were present. A talk on "The Traction System of the Denver City Tramway Company" was given by Mr. Norman Read, electrical engineer for that company. Mr. Read divided his talk into three parts; namely, the road-bed, the power-house and feeder system, and the rolling stock. Under the first head he mentioned the length of the combined system, the size of the rails, the method of laying the pavement, and electrically brazed bonds. Under the second head he discussed the generating system, the distributing and trolley systems, lightning protection, and the method of overcoming electrolysis of underground pipes. Under the third head the design of cars was discussed, and the advantages of light, side entrance, narrow truck cars were shown. A brief outline was also given of the trailer method operated during rush periods and the telephone dispatching system.

STATE UNIVERSITY OF IOWA

The State University of Iowa Branch has held four meetings since the opening of the school season this fall, as follows: October 23, November 13, November 27, and December 11.

On October 23 the paper on "Unified Electric Systems" by W. B. Jackson, was presented in abstract and discussed by Mr. James Ehret.

On November 13 the paper on "The Cost of Industrial Power" by A. E. Hibner, was presented by Mr. R. M. Ellinghouse.

On November 27 the paper on "Large Electric Hoisting Plants" by W. Sykes, was presented by Mr. J. E. Everson.

On December 11 a paper entitled "The Edison Feeder and Main System" by F. L. Dyer, was presented by Mr. L. F. Hatz.

The Branch held its annual meeting last May, and the following officers were elected at that time to serve for this year: Chairman, Mr. L. J. Keiser; vice-chairman, Mr. J. A. Crew; secretary-treasurer, Professor A. H. Ford.

KANSAS STATE AGRICULTURAL COLLEGE

This Branch held its regular meeting in the chemistry lecture room on December 5. Mr. C. C. Witt, engineer for the Kansas Public Utilities Commission, addressed the students on "The Regulation of Public Service Corporations." Thirty-five members were present.

STATE UNIVERSITY OF KENTUCKY

The November meeting of the State University of Kentucky Branch was held in the mechanical hall on November 27. A paper on "Alternating-Current Apparatus Troubles" was read by Mr. J. W. Cary.

UNIVERSITY OF MAINE

The University of Maine Branch held its first meeting for the year 1911–1912 on November 14. The following officers were elected: Chairman, Benjamin Haskell; vice-chairman, G. G. Tilley; secretary, John E. Ash; treasurer, C. B. Cleaves; executive committee, W. E. Parker, G. B. Spear, R. W. Wetherbee, A. T. Childs.

UNIVERSITY OF MICHIGAN

The University of Michigan Branch held its regular monthly meeting on December 5, with an attendance of 65 members. After the transaction of several business matters, including the appointment of membership, program and publicity committees, Mr. G. N. Lemmon, electrical engineer for the Michigan United Railway, gave an address on "Rehabilitation of Power Plants and Lines."

UNIVERSITY OF MISSOURI

The regular meeting of the University of Missouri Branch was held on November 20, and was devoted to the subject "High Efficiency Lamps." Papers were presented by Mr. I. J. Buergey and T. R. Tate. Mr. Buergey gave data on manufacture and operating characteristics. He also gave several calculations of the total cost of illumination showing the comparative merits of the different types of lamps.

Mr. Tate took up the effects of the high efficiency lamp on the cost of power. He also gave figures showing the increase in the amount of power sold in St. Louis, and described the practice of various central station companies in regard to renewals.

NEW HAMPSHIRE COLLEGE

The first meeting of the New Hampshire College Branch for this season was held in Conant Hall on Monday evening, December 11. Mr. H. L. Coburn, chief designer of the Ambursen Hydraulic Construction Company, of Boston, delivered an illustrated lecture on " The Design of Dams." Mr. Coburn explained the causes of the failure of the Johnstown and Austin dams and the difference in the design of these two dams as compared with the present reënforced concrete dam. By means of lantern slides, several types of the modern Ambursen dam, when designed to meet varying conditions, were shown. Other views were shown of dams which had failed, with an explanation as to the probable cause of the failure. Thirty members were present.

N. C. COLLEGE OF A. AND M. ARTS

The N. C. College of A. and M. Arts held its monthly meeting on November 22. Mr. E. F. Alexanderson's paper on " Magnetic Properties of Iron at Frequencies up to 200,000 Cycles ", printed in the December PROCEEDINGS, was read in abstract by Mr. R. Giersch.

OREGON AGRICULTURAL COLLEGE

The regular meeting of the Oregon Agricultural College Branch was held on November 16. It was voted to hold meetings on the second Thursday evening of each month at 7:30 p.m., and it was decided that an effort will be made to obtain outside speakers, particularly practising engineers, to address meetings. An illustrated lecture on " Perpetual Motion " was delivered by Dr. W. Weniger.

UNIVERSITY OF OREGON

The first meeting of the University of Oregon Branch for the school year was held on November 14. Professor Dearborn presented a paper on " The Power Systems of Oregon." Professor Dearborn, through his work with the State Public Service Commission during the past summer, has had an excellent opportunity to obtain first-hand knowledge of the subject. There were 25 members at the meeting.

PURDUE UNIVERSITY,
LAFAYETTE, IND.

At a meeting of the Purdue University Branch held on November 9, a symposium on the problems of high tension transmission was presented, under the following heads: " Corona Losses ", by Mr. A. E. Hague; " Line Equipment ", by Mr. F. A. Mayfield, " Lightning Protection ", by Mr. Grand-Girard.

Mr. Hague's paper described the appearance of corona and the conditions under which it is produced, together with the laws of its production and the laws of losses occasioned by the corona in so far as they are known.

Mr. Mayfield described the considerations governing a choice between steel towers and wooden poles, pointing out the limitations imposed by the value of the transmission voltage and climatic conditions.

Mr. Grand-Girard's discussion of lightning protection included a detailed description of horn, multiple gap, and aluminum cell arresters, the principles of their operation, and their adaptability of various classes of service.

After the presentation of the papers a demonstration of certain phenomenon of corona was given by Professor Harding, on a short transmission line installed in the lecture room for the purpose. The efficacy of guard rings in protecting insulators against power arcs caused by lightning was illustrated by causing discharges to ground over insulators with and without such protection.

ROSE POLYTECHNIC INSTITUTE, TERRE HAUTE, IND.

The first meeting of the Rose Polytechnic Institute Branch was held on Thursday evening, December 7. Officers for the year were elected as follows: Executive Committee, Dr. C. L. Mees, chairman, Professor C. C. Knipmeyer, and Messrs. Henry L. Yingling and Claude E. Reese; Chairman of the Branch, Mr. Jerry H. Service, Jr.; secretary, Mr. David W. Jones. It was voted that meetings be held monthly, preferably on Friday evening, and that the next regular meeting be held on January 5. The date and hour of succeeding meetings are to be decided upon by the program committee. At the conclusion of the work of reorganization the members were addressed by Dr. Mees, and Professors Wagner, Knipmeyer and Wischmeyer, on early developments in electrical engineering.

STANFORD UNIVERSITY, CAL.

A meeting of the Stanford University Branch was held on November 16. Mr. M. Wenk read a paper on " Metallic Filament Lamps."

SYRACUSE UNIVERSITY

The regular monthly meeting of the Syracuse University Branch was held on November 23, in the College of Applied Science, Dean W. P. Graham presiding. Mr. B. H. Shepard, commercial engineer of the local office of the New York Telephone Company, discussed some of the late features of telephone engineering, including phantom circuits, Pupin coils, the underground from New York to Washington, and distribution from block interiors. Mr. Shepard also spoke of the opportunities for young engineers in the telephone business.

THROOP POLYTECHNIC INSTITUTE, PASADENA, CAL.

The regular monthly meeting of the Throop Polytechnic Institute Branch was held on November 3, with a total attendance of 44 students and visitors, indicating increasing interest in the work of the Branch. Mr. Kreitler, of Pasadena, Cal., gave a talk on " Road Construction." The talk was followed by a paper on " The Roosevelt Dam and Its Effects Upon the Irrigated Districts ", which was read by Mr. F. C. Miller.

A short business session followed the meeting, at which Mr. Frank C. Miller was elected chairman of the Branch for the rest of the school year.

WORCESTER POLYTECHNIC INSTITUTE

The Worcester Polytechnic Institute Branch, at its meeting held on December 8, was addressed by Mr. Day Baker, of Boston, on " The Progress and Future of the Electric Vehicle." The lecture, which lasted two hours, was illustrated by over one hundred lantern slides, showing the development from the early electric omnibus and wheel chair up to the modern ten-ton truck and the pleasure vehicle. The construction of the modern truck was considered to some extent. The ability of the electric truck to carry heavy loads and climb steep grades was brought out in a series of slides. Mr. Baker did not attempt in any way to belittle the gasoline truck, but on the contrary said that it was very satisfactory in its own field; namely, the long haul, but that it could not compete successfully with the electric vehicle on short hauls.

YALE UNIVERSITY, NEW HAVEN, CONN.

The Yale University Branch held its third meeting on Wednesday evening, November 22. The speaker of the evening was Mr. Oliver S. Lyford, Jr., consulting engineer of Westinghouse, Church, Kerr and Company, New York City. The subject of Mr. Lyford's address was " The Electrification of the Long Island Railroad." Mr. Lyford gave an outline of the general scheme of electrification, involving power station, third-rail conductor, transmission lines, sub-stations, and car equipment. The lecture was illustrated by a number of lantern slides which showed the work in various stages of development.

The fourth meeting of the Branch was held on Friday evening, December 8. In the absence of Chairman Beck, Mr. S. A. Griswold was elected temporary chairman. Papers on "New Haven Street Railways" and "Modern Street Illuminants" were read by Mr. J. MacArthur, 12s, and Mr. E. S. Hastings, 12s, respectively. In the discussion which followed, Mr. H. W. Hillman, of New Haven, gave an interesting history of the magnetite arc light and the difficulties experienced in perfecting it. Thirty-five members and visitors attended the meeting.

Personal

MR. M. A. MARCA-ROMERO, of Lima, Peru, has been appointed by the Peruvian Government professor of electricity, chemistry and physics at the Peruvian Military Academy.

MR. S. H. GRAUTEN, formerly in the electrical department of the New York Central and Hudson River Railroad Company, Grand Central Terminal, New York, was recently appointed testing engineer for the Isthmian Canal Commission, with headquarters at Culebra, Canal Zone.

MR. GEORGE B. TRIPP, formerly general manager of the Colorado Springs Light, Heat and Power Company, has resigned his position to become vice-president of the Harrisburg Light, Heat and Power Company. Mr. Tripp will reside at Harrisburg and direct the operations of the company.

MR. CARROLL R. PHENECIE, who for the past eight years has been electrical engineer for the Chicago and Milwaukee Electric Railroad Company, and the past year and a half has also been master mechanic, has resigned to accept the position of electrical engineer for Mr. Clement C. Smith, of Milwaukee, in connection with a large number of lighting and power companies in Illinois, Wisconsin and Minnesota.

MR. JEAN BART BALCOMB, consulting engineer, of Chicago, has accepted the position of executive engineer for the Alvord Valley Irrigation Company, which has been formed, following an examination and report on a tract of land in Oregon by Mr. Balcomb, to develop an irrigation project and generate and sell electrical power to be used for irrigation purposes. The appointment will not interfere with Mr. Balcomb's general practice as consulting engineer.

MR. S. GEORGE FREUND, who since 1901 has been connected with various interests in New York City, has established offices at 100 Broadway, New York City, and Berlin, Grunewaldstr. 99, and will conduct a practice as consulting commercial engineer for the foreign trade. Mr. Freund will act as an intermediary between American and foreign, especially German, industries, in the mutual extension of their technical-commercial relations, and will assist American and German manufacturers in matters relating to import, export, manufacture, and the exploitation of patents.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Congreso Cientifico (1° Pan Americano). Ciencias Naturales, Antropologicas y Etnologicas. Tomo I. Santiago de Chile, 1911. (Gift of Congreso Cientifico (1° Pan Americano.)

Crude Rubber and Compounding Ingredients. Ed. 2. By H. C. Pearson. New York, 1909. (Purchase.)

Electric Power on the North-East Coast. London, 1911. (Gift of North East Coast Power System Co.)

Electric Railway Engineering. By C. F. Harding. New York, McGraw-Hill Book Co., 1911. (Purchase.)

Graphical Solution of Problems Involving Plane Surface Lighting Sources. The Law of Conservation as Applied to Illumination Calculations. Absorption of Light Method of Calculating Illumination. Bearing of Reflection on Illumination. By A. S. McAllister. n.p. n.d. (Gift of author.)

Graphite. Vols. 9, 12. Jersey City, 1907, 1910. (Gift of Joseph Dixon Crucible Co.)

Induction Motor. By B. F. Bailey. New York, McGraw-Hill Book Co., 1911. (Purchase.)

L'Internationalisme Scientifique (Sciences Pures et Lettres). By P. H. Eijkman. La Haye, 1911. (Gift of Oficejo de la Fondajo por Internacieco.)

Der Kautschuk und seine Prüfung. By F. W. Hinrichsen und K. Kemmler. Leipzig, 1910. (Purchase.)

Magnetic Circuit. By V. Karapetoff, New York, McGraw-Hill Book Co., 1911. (Purchase.)

New York State Public Service Commission. First District. Report, Volume I, 1910. Albany, 1911. (Exchange.)

New York (State) Public Service Commission, Second District. Annual Report. 4th, 1910, Vols. 1–2. Albany, 1911. (Exchange.)

Principes de la Technique de l'Eclairage. By L. Bloch. Translated from the German into French by G. Roy. Paris, Gauthier Villars, 1911. (Gift of Publisher.)

This book differs from most books on lighting in omitting all descriptive matter and treating of the subject entirely from the technical side. The work reprints material contributed by Dr. Bloch to the *Journal fur Gasbeleuchtung* and the *Electrotechnische Zeitschrift*, and summarizes the experience in installation for the *Berlin Elektrizitatswerke*.—W.P.C.

Principles of Electrical Engineering. By H. Pender. New York, McGraw-Hill Book Co., 1911. (Purchase.)

Il riempimento dei diagrammi di carico. " Report submitted to the Turin International Congress of Electricity on Theme 21" By G. Sartori. Torino, 1911. (Gift of author.)

Zeitschrift fur Elektrochemie und angewandte physikalische chemie. General register. Band 1–10, 1894–1904. Halle a. S., 1911. (Purchase.)

Trade Catalogues

Allgemeine Elektricitäts Gesellschaft, Berlin. Measuring instruments. 2 pp.

———Commercial trucks and their economy. 16 pp.

———New overhead construction material. 4 pp.

———New electric railway motors. 4 pp.

Beleuchtungskorper Gesellsch. Berlin. Various lighting systems. 32 pp.

Crocker-Wheeler Co., Ampere, N. J. Bull. No. 139—Belt driven d.c. generators and motors. 15 pp.

———Bull. No. 140—Power equipment of a concentrating plant. 7 pp.

General Electric Co., Schenectady, N.Y. Bull. No. 4860—Generators for electrolytic work. 9 pp.

———Bull. No. 4885—Thomson watt-hour meter. 6 pp.

———Bull. No. 4886—Electricity in coal mines. 59 pp.

———Bull. No. 4889—Commutator-grooving machines. 3 pp.

———Bull. No. 4891—Electric railway equipment. 53 pp.

———Bull. No. 4894—Cylinder controllers for railway service. 16 pp.

Westinghouse, Church, Kerr & Co., New York Central power stations. 49 pp.

United Engineering Society

Deutschen Buchdrucker Berufs Genossenschaft. Geschafts Bericht 1910. Frankfort on Main, 1910. Gift.

Manuals of Safety. Alcoholism in Industry. Some European Methods of Prevention. New York, 1911. (Gift of American Museum of Safety.)

Michigan Gas Association. Proceedings of Annual Meeting. 20th Detroit, 1910. (Gift of Michigan Gas Association.)

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NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

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*Deceased.

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ROBERT JULIAN SCOTT, Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta............Jan. 19, '04	A. M. Schoen.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore..........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	William L. Hooper.	G. A. Rodenbaeck, 84 State St., Boston, Mass.
Chicago....................1893	J. G. Wray.	
Cleveland.........Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	O. H. Ensign.	E. R Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Madison...........Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Lynn..............Aug. 22, '11	E. E. Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass.
Mexico...........Dec. 13, '07	W. H. Fiske.	H. S. Foley, Apartado 124 Bis., Mexico, D. F.
Milwaukee........Feb. 11, '10	F A. Vaughan	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric Co., Minneapolis, Minn.
Philadelphia.......Feb 18, '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg..........Oct 13, '02	K C. Randall.	E. L Farrar, G. E. Co, Oliver Bldg., Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore......May 18, '09	F. D. Weber.	H. R. Wakeman, 604 Electric Building Portland, Ore.
San Francisco.....Dec. 23, '04	S B. Charters.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo
Toledo............June 3, '07	George E. Kirk	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O
Toronto...........Sept. 30, '03	A L Mudge.	Valentine Boy , 212 King St, West, Toronto, Ont.
Urbana...........Nov. 25, '02	E. H. Waldo.	F G Willson, University of Illinois, Urbana, Ill
Vancouver.........Aug 22, '11	F D. Nims.	E M Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B C.
Washington, D. C...Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington D C

Total. 27.

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Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L R Hulse, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio
Cincinnati, Univ. of..Apr. 10, '08	W. H. Jefferson.	Oscar Plueddemann, University of Cincinnati, Cincinnati, O.
Colorado State Agricultural College.......Feb. 11, '10	D. E. Byerley.	A A Catlin, 626 So Meldrum St., Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	L. J. Kieser.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.Jan. 10, '08	B. F. Hillebrandt	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of................Oct. 14, '10	W H Jae le.	J H Gaiser, 341 Harrison Ave., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa.
Lewis Institute. .....Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	Benjamin Haskell	John E. Ash, University of Maine, Orono, Maine
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	J Glen Luther.	J. A .Thaler, Montana State College, Bozeman, Mont
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ......Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.....Oct. 13, '11		
Oregon State Agr. Col.Mar. 24, '08	H Belknap.	W R Varner, Oregon St. Agric. College, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R H. Dearborn	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.........Jan. 26, '03	C. F. Harding.	A L Topping, Purdue University, Lafayette, Ind
Rensselaer Polytechnic Institute...........Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N Y
Rose Polytechnic Inst.Nov. 10, '11	Jerry H. Service, Jr.	David W. Jones, 911 North 8th Street, Terre Haute, Ind.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.......Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N Y.
Texas, Univ. of.......Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.............Oct. 14, '10	Frank C. Miller.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena Cal
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	O Krupp, 65 North Bend St., Burlington, Vt
Wash., State Coll. of..Dec. 13, '07	M K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Irwin L Cheney	P S Stevens, Washington University, St Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester Mass.
Yale University......Oct 13, '11		

Total, 39

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of
THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol XXXI **February, 1912** No. 2

Next Regular Meeting of the A. I. E. E., New York, February 9, 1912

The two hundred and sixty-eighth meeting of the A.I.E.E. will be held in the Auditorium of the Engineers Building, 33 West 39th Street, New York, on Friday, February 9, 1912. A paper will be presented by Mr. George I. Rhodes of the Interborough Rapid Transit Company, entitled "A Study of Power Costs with Reference to Load Curve and Overload Economies." The paper is published elsewhere in this issue of the PROCEEDINGS.

The meeting will be called to order punctually at 8:15 p.m. in order that the discussion may be closed at 10:00 o'clock, after which those present will adjourn to the Institute headquarters on the 10th floor, where a smoker will be held.

Future Institute Meetings

The Meetings and Papers Committee of the A.I.E.E. has completed its schedule of meetings for the season of 1912, which are as follows:

The two hundred and sixty-eighth meeting will be held in New York, February 9, 1912, at which a paper by Mr. G. I. Rhodes will be presented as announced elsewhere in this issue.

The two hundred and sixty-ninth meeting will be held in New York, on March 8th, and will be under the auspices of the High Tension Transmission Committee. The complete program for this meeting has not yet been decided upon, but should the number of papers presented warrant it, the meeting will be divided into an afternoon and an evening session.

The two hundred and seventieth meeting will be held in New York, April 5, 1912, and will be under the auspices of the Railway Committee. The papers for this meeting have not yet been announced. The change of date from the usual second Friday in the month to the first Friday in this case, has been made necessary on account of two other April meetings, as shown in this schedule. There will be afternoon and evening sessions.

The two hundred and seventy-first meeting will be a Pacific Coast meeting at Portland, Ore., April 16 to 20, 1912. This meeting will be similar in its scope to those held on the Pacific Coast in San Francisco in 1910 and in Los Angeles, 1911.

The two hundred and seventy-second meeting of the Institute will be held at Pittsburgh, Pa., April 25 to 27, 1912. This meeting will be under the auspices of the Industrial Power Committee, which is now engaged in preparing a program for the meeting. The Association of Iron and Steel Electrical Engineers will join with the Institute in this meeting.

The two hundred and seventy-third meeting will be held at Schenectady early in May, 1912. The exact date of this meeting has not been definitely fixed.

The two hundred and seventy-fourth meeting will be held in New York, May 21, 1912. This is the Annual Meeting of the Institute, at which the annual reports will be presented and the results of the election will be announced.

The Annual Convention of the Institute, as previously announced, will be held in Boston, Mass., June 25 to 28, 1912. The selection of Boston for the next annual meeting place of the Institute has been heartily endorsed by a large proportion of the membership, and the local authorities in Boston, as well as several local organizations, have kindly offered to coöperate in making the meeting there a success. The selection of this location assures a large attendance.

A. I. E. E. Meeting in New York, January 12, 1912

The two hundred and sixty-seventh meeting of the A.I.E.E. was held in the Engineers Building, New York, Friday evening, January 12, 1912. The meeting was called to order at 8:15 o'clock by Mr. D. B. Rushmore, who occupied the chair temporarily during President Dunn's absence at another meeting.

Mr. Rushmore introduced Mr. Percival R. Moses, the speaker of the evening, who abstracted his paper on "Some Notes on Isolated Plants." At the close of Mr. Moses' remarks President Dunn took the chair, and the discussion which followed was participated in by Messrs R. P. Bolton, John C. Parker, Arthur Williams, George W. Martin, Charles K. Nichols, John W. Lieb, Jr., and Percival R. Moses.

At the close of the discussion a vote of thanks was tendered to the author for his interesting paper and also to Mr. R. P. Bolton who was present by invitation to discuss the paper.

After the close of the discussion President Dunn announced that the Board of Directors at its meeting on the afternoon of January 12 had unanimously decided to recommend to the membership amendments to the Constitution providing for an additional grade of membership. Further details in regard to the proposed amendments will be found elsewhere in this issue.

President Dunn also announced the appointment of Mr. F. L. Hutchinson as Secretary of the Institute, to fill the unexpired term of Mr. Pope, who resigned some time ago, and stated that the Board also decided to recommend him for election by the membership for the coming full term. The technical meeting then adjourned.

Over 200 of the members at the technical session then gathered in the Institute offices on the 10th floor, where the social function following the regular meeting was held.

New Section at Indianapolis and Lafayette, Ind.

On the petition of 29 Members and Associates, the organization of a joint Section of the American Institute of Electrical Engineers at Indianapolis and Lafayette, Ind., was authorized by the Institute Board of Directors at its meeting held on January 12, the new Section to be known as the Indianapolis-Lafayette Section. This is the second joint Section authorized, the other being the Detroit-Ann Arbor Section. In both cases a manufacturing town is combined with a college town, a combination which it is believed will produce an active Section. This increases the number of Sections to 28, which with the 39 Branches makes a total of 67 local organizations.

Year Book for 1912

A new edition of The Institute Year-Book for 1912 was published the latter part of January. The book is intended principally for use in connection with the work of the membership committee. The contents include: list of Institute officers and committees; local officers of sections and branches; alphabetical and geographical lists of Members and Associates; list of enrolled students; the constitution and by-laws; directors' annual report for year ending April 30, 1911, and also, for the use of non-members, general information regarding the object, scope and work of the Institute.

Any Member or Associate may obtain a copy upon application to the Secretary's office by mail or in person.

CONSTITUTIONAL AMENDMENTS

Notes on the Proposed Constitutional Amendments Providing for an Additional Grade of Membership

In this issue of the PROCEEDINGS members will read in the resume of business done at the meeting of the Board of Directors on January 12th, a notice of the final adoption by the Board of a group of amendments to the constitution to provide an additional grade of membership in the Institute. To become effective, at least 30 per cent of the membership must vote upon them, and, of this vote, 75 per cent must be affirmative. In due course the text of the amendments in their formal form will be mailed to each member.

In order to give advance information, it has been thought desirable to reprint in this issue of the PROCEEDINGS portions of the constitution as it would be if the amendments were approved by the membership. The new parts are given in Italics. For those who do not care to go sufficiently into details to read the constitution, (which however is recommended), a brief description of the effect of the amendments follows:

It is hard to realize how rapid has been the Institute's growth. With this growth to a total of now over seven thousand members have come new problems which the smaller Institute of early days did not have to meet. On the one hand, the desire of enhancing the value of what is colloquially called " Full Membership " has led to the tightening of the lines of restriction so that a large number of members, although professional electrical engineers with records of considerable experience, and comparing favorably in professional standing with members in the highest grades of other engineering societies, have been excluded. For these there has been no other classification than " Associate," for which the qualification is not at all professional and was never intended to be, the conditions of admission being only an interest in or a connection with the study or application of electricity.

The recognition of the justice of the claims of the professional element among the present Associates, and the desire to admit as many of them as possible to full membership, has been a counter-influence against the raising of the standard of full membership as high as the general demands of the Institute have seemed to desire it, since the professional element—whether associate members or full members—recognizes that the standing of the society as a whole is judged largely by the standing of its highest grade, and, for the sake of the Institute's prestige, have wished this grade to be as high as possible; also, those professional electrical engineers who are Associates look forward to the time when their experience and quality of record will entitle them to admission to full membership.

For four years committees have been appointed to investigate and report on means for increasing the solidarity of the Institute and its *esprit de corps* by providing for each kind of member an appropriate classification that would fit his relation to the society as a whole and, at the same time, enable a very high standard of requirement for the highest grade to be maintained. Building upon the labors of the previous committees, this year's committee on an " Additional Grade of Membership " has reported the present amendments.

Divested of their formal phraseology, they provide a new grade called " Fellow " for the highest grade; leave the present grade called " Member," with certain modifications of the requirements for admission, but without increase of dues or of admission fees;

and make no change in the requirements for admission or the dues of the grade of "Associate." The latter is left, as it is at present, for professional electrical engineers who have only begun their experience, and for that large and important part of the membership of the Institute which, while not professional, is, nevertheless, an essential factor in the Institute's success. It brings into the Institute lawyers, bankers, business men, authors, and friends of the art of electrical engineering who, besides the actual benefit of their membership, give a balance to the Institute's discussions and affairs and enhance, in a personal way, the character of its meetings, conventions and other interests.

For the grade of Fellow there is in effect no increase in the quality of experience required over that for the present grade of Member. The length of such experience in active professional practice, however, must be ten years where it is now only five, and the time in responsible charge of work must be three years where it is now two. The dues are raised from $15.00 to $20.00 per year, and the life membership fees from $200.00 to $250.00.

On application to the Secretary, which is principally for the purpose of securing the Member's acceptance of the increased financial obligation, any present Member, prior to May 1, 1913 (over a year hence), has the right, without payment of transfer fee or increase of life membership fee, to be transferred to the grade of Fellow, provided he refers to five Members or Fellows who, upon inquiry, shall certify that he meets the requirements of the grade of Fellow as stated in the constitution.

It will be seen that in the case of those who are already Members at the time the amendments are adopted, the transfer to the grade of Fellow does not go through the Board of Examiners in the usual form of routine. The labor of passing upon such transfers as would take place in connection with passing the large numbers of existing Members over into the grade of Fellow would be more than the Board of Examiners or, in fact, any other committee of the Institute could undertake. In the Amendments it is left to five of a Member's friends in the society, who, by certifying to the facts of his experience, act as a Board of Examiners.

Similar provisions apply to transfer from the grade of Associate to that of Member, upon certification, in this case, by four Fellows or Members that the Associate meets the requirements of the grade of Member as stated in the Constitution. The requirements for this grade have been somewhat reduced, but not beyond a point that will preserve a favorable comparison with the same grade in other leading engineering societies.

Responsible charge of work for a specified time is no longer insisted upon provided the applicant, has designed and taken responsibility for, under general direction, important electrical engineering work, and has been in the active practice of his profession for five years as an electrical engineer.

The dues of Members have not been increased, nor have the life membership fees; and transfers from the grade of Associate to that of Member, on application prior to May 1, 1913, may be had without payment of transfer fees or increase of life membership fees.

A new feature is direct admission into any grade of membership without passing through the lower grades, provided the applicant rigidly fulfills the requirements of the grade into which he seeks admission.

It is also provided that membership in an equivalent grade in a national society of an allied branch of engineering shall be credited as the equivalent of five years' experience in the case of Fellow, and two and one-half years' experience in the case of Member, in determining whether an applicant meets the requirements of the Institute.

In the case of a teacher of electrical engineering, who, in order to be eligible to the grade of Fellow, must have had ten years of experience, such experience as he has had as a professional electrical engineer before entering the profession of teaching shall be credited as the equivalent of the same number of years' experience as a teacher.

Outside of the strictly professional class, provision is made to admit to the grade of Fellow persons who have done notable original work in electrical science of a character to give them a recognized standing equivalent to that required for the grade of Fellow, and also persons regularly engaged in electrical work for at least ten years, who by inventions or by special proficiency in contributions to electrical science or the electrical arts or electrical literature, have attained a standing equivalent to that required for the grade of Fellow. These provisions, which are to be interpreted by the Board of Examiners, tend to broaden the character of the grade of Fellow, but by no means to reduce its caliber.

It is also provided that admission to the grade of Member may be had by persons regularly employed in electrical or closely allied work for at least five years, who, by inventions or by proficiency in electrical science, the electrical arts or electrical literature, or as executives of electrical enterprises of large scope, have attained a standing equivalent to that required for the grade of Member. In the case of an executive, the applicant must be qualified to take responsible charge of the broader features of electrical engineering involved in the work under his direction. This admits to membership men whose training and practice have not been entirely engineering, but who have risen to executive charge of engineering enterprises through great ability, and who are of a caliber and personality that would add to the distinction of that grade of membership.

No distinction is made between Fellows, Members or Associates in the right to vote, each casting one ballot.

A word may be desirable in regard to the name "Fellow." The greatest confusion exists at present in the designation for the various grades of membership in the leading engineering societies, and it may be interesting to mention in passing that the Institute is the only great engineering society that has not already provided more than two grades of membership.

Strict rules have been made prohibiting the use by Associates of the designation Member, or of the designation Associate Member, a term used in some other societies, but as Associates and Associate Members are "members," and it is impossible, under many circumstances, to refer to them as anything else, ambiguity often exists, and an Associate Member, or an Associate, is many times unintentionally put in the position of appearing to claim a higher rank than is his right.

The term Junior Member is objectionable because of the implication that its principal qualification is one of age.

There has been in growing use for many years in England the designation Fellow to denote the highest grade of membership in learned bodies; this undoubtedly following the precedent set by the Royal Society. The number of British scientific and professional institutions that have adopted the term is already large, and includes the most distinguished bodies in the United Kingdom. Americans followed this precedent a number of years ago—first in Canada and then in the United States—where the term has been gradually coming into use, so that at present "Fellow" is the designation of the highest grade in sixteen scientific, learned and professional bodies in the United States. Its use is increasing, since not only does it help to avoid the confusion among the names of different varieties of membership that now exists but it brings about the introduction of a designation that has never been used except to represent a high honor, and that carries with it an association of distinction.

The American Institute of Architects,

a most conservative and important professional body with similar ideals to our own, has adopted it for the designation of its highest grade, and it has been felt by the Board of Directors that the Institute's adoption of it would add to the Institute's prestige and add to the precedent that American societies have been setting for the general use of the term. A partial list of the names of the societies employing the term Fellow is shown in the list of Fellows, accompanying the portions of the constitution affected by the Amendments.

The Board of Directors has given careful consideration to the proposed Amendments and to the welfare of the Institute, which, in their opinion, demands their adoption. Four Committees during four successive years have worked upon the problem, and the present Amendments have been before the Board for some time. They have received certain modifications which the Board contributed, in addition to modifications contributed by various leading members of the Institute whose judgment has been consulted. The action of the Board in recommending the Amendments to the membership as something that will add to the Institute's strength, prestige and usefulness, was unanimous.

GANO DUNN.

Parts of Constitution Affected by Proposed Additional Grade of Membership Amendment*

ARTICLE II.

MEMBERSHIP

3. The membership of the INSTITUTE shall consist of Honorary Members, *Fellows*, Members and Associates. *Fellows*, Members and Associates shall be equally entitled to all the rights and privileges of the INSTITUTE, excepting that *Fellows* only shall be eligible to *the office of President; and Fellows and Members only shall be eligible to the offices of Vice-President, Manager and Treasurer. Fellows and* Members shall be entitled to a diploma. Honorary Members shall be entitled to all the rights and privileges of the INSTITUTE, except the right to vote for officers and to hold office.

4. *A Fellow shall not be less than thirty-two years of age and shall be either:*

a An electrical engineer by profession. As such he shall be qualified to design and to take responsible charge of important electrical work; he shall have been in the active practice of his profession for at least ten years, and shall have had responsible charge of important electrical work for at least three years.

When the applicant holds, in a principal national society of an allied branch of engineering, membership of a grade for which the qualifications indicate a standing equal to that required for the grade of Fellow herein, such membership shall be considered equivalent to five of the requisite ten years of active practice of the electrical profession.

b A professor of electrical engineering or of electrical science. As such he shall have attained special distinction as an expounder of the principles of electrical science and of electrical engineering; he shall have had at least ten years' experience as a teacher of electrical subjects, and shall have had responsible charge for three years, in an electrical course of a principal school of engineering. Any years of experience as defined in paragraph "a" that the applicant may have had as an electrical engineer shall be considered the equivalent of the same number of years of experience as a "teacher of electrical subjects."

c A person who has done notable original work in electrical science of a character to give him a recognized standing equivalent to that required for Fellows under paragraphs "a" and "b".

d A person regularly engaged in electrical work for at least ten years, who, by inventions or by special proficiency in contributions to electrical science or the electrical arts or electrical literature has attained a standing equivalent to that

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*Unchanged parts of present constitution are printed in Roman; changes and additions are printed in Italics.

required for Fellows under paragraphs " a " and " b ".

5. A Member shall not be less than twenty-seven years of age, and shall be *either:*

a An electrical engineer by profession. As such, under general direction, he shall have designed and taken responsibility for important electrical engineering work; he shall have been in the active practice of his profession for at least five years.

When the applicant holds, in a principal national society of an allied branch of engineering, membership of a grade for which the qualifications indicate a standing equal to that required for the grade of Member herein, such membership shall be considered equivalent to two and one-half years of the requisite five years in active practice of the electrical profession.

b A teacher of electrical engineering or of electrical science. As a teacher of electrical subjects, he shall have had at least five years' experience in a school of recognized standing. Any years of experience the applicant may have had as an electrical engineer shall be considered the equivalent of the same number of years of experience as " a teacher of electrical engineering or of electrical science."

c A person regularly employed in electrical or closely allied work for at least five years, who, by inventions or by proficiency in electrical science, the electrical arts, or electrical literature, or as an executive of an electrical enterprise of large scope, has attained a standing equivalent to that required for Members under paragraphs " a " and " b ". In the case of such an executive the applicant must be qualified to take responsible charge of the broader features of electrical engineering involved in the work under his direction.

6. An Associate shall not be less than twenty-one years of age *and shall be either:*

a An electrical engineer by profession.

b A teacher of electrical subjects.

c A person who is interested in, or connected with, the study or application of electricity.

7. *In all cases, graduation from the electrical course of a school of engineering of recognized standing shall be considered the equivalent of one year's electrical experience.*

Special Section. Any person who shall be a Member at the time this group of amendments is adopted, shall, on written request to the Secretary prior to May 1, 1913, *without the payment of the transfer fee, or increase of life membership fee, have the right to become a Fellow provided he refers to at least five Fellows or Members, who, upon inquiry, shall certify that he meets the requirements of the grade of Fellow, as herein defined.*

Any person who shall be an Associate at the time this group of amendments is adopted, shall, on written request to the Secretary prior to May 1, 1913, *without the payment of the transfer fee, or increase of life membership fee, have the right to become a Member, provided he refers to four Fellows or Members who, upon inquiry, shall certify that he meets the requirements of the grade of Member, as herein defined.*

The dues of Members and Associates transferred under the provisions of this special section shall not be increased until May 1, 1913.

ARTICLE III.

ADMISSION, TRANSFER AND EXPULSION OF MEMBERS

10. *Applications may be made for admission to any grade of membership. Applicants shall give references to members of the Institute as follows:*

For the grade of Fellows, to five Fellows.

For the grade of Members, to four Fellows or Members.

For the grade of Associates, to three Fellows, Members or Associates.

Application may be made for transfer from the grade of Member to the grade of Fellow, and from the grade of Associate to the grade of Member or to the grade of Fellow.

Should an applicant for the grade of

Fellow, either for direct admission or for transfer, certify that he is not personally known by five Fellows, the Board of Examiners may accept, in place thereof, references to five professional engineers of standing.

11. *Regulations as to the form of applications, and of transfers from one grade to another, and as to the method of their consideration, shall be prescribed in the by-laws.*

12. The reference to *Fellows* to whom an applicant is personally known may be waived in case of foreign applications; but the applicant shall in that case refer to at least two professional engineers of recognized standing.

13. The Secretary shall issue at stated intervals to each *Fellow*, Member and Associate whose address is known, a list of new applications for admission to the INSTITUTE, with the request that *they* make written communication to the Board of Directors, in case of objection to any of the candidates named. The Board of Directors shall not act upon any name until at least twenty days after the date of issue of said list.

14. All elections and transfers shall be by vote of the Board of Directors; two negative votes shall exclude a candidate.

17. Upon the written request of ten or more *Fellows*, Members or Associates that, for cause stated therein, a *Fellow*, Member or Associate of the INSTITUTE be expelled, the Board of Directors shall consider the matter, and if there appears to be sufficient reason, shall advise the accused of the charges against him. He shall then have the right to present a written defence, and to appear in person or by duly authorized representative before a meeting of the Board of Directors, of which meeting he shall receive notice at least twenty days in advance. Not less than two months after such meeting, the Board of Directors shall finally consider the case, and if in the opinion of the Board of Directors a satisfactory defence has not been made, and the accused member has not in the meantime tendered his resignation, he shall be expelled.

ARTICLE IV.

DUES

18. *The entrance and transfer fees, payable on admission to the Institute, or upon transfer, shall be as follows:*

Admission to the grade of Fellow, twenty (20) dollars.

Admission to the grade of Member, fifteen (15) dollars.

Admission to the grade of Associate, five (5) dollars.

The transfer fee from one grade of membership to another shall be the difference between the corresponding admission fees.

19. *The annual dues shall be as follows:*

For Fellows, twenty (20) dollars.

For Members, fifteen (15) dollars.

For Associates, ten (10) dollars.

22. *A Fellow, Member, or Associate, in good standing, by the single payment of $250.00, $200.00, or $150.00, respectively, shall become exempt from all future payment for dues in his grade. On transfer to a higher grade, Associates and Members shall pay the usual transfer fee and the difference between the respective life membership fees. The Life Membership fees thus paid shall be invested as a special fund to be known as the "Life Membership Fund," from which there shall be taken out and appropriated for the general expenses of the Institute each year until the death or resignation of said Fellow, Member, or Associate, five per cent of the Life Membership fee corresponding to his grade of membership, or of such less sum as may remain. Upon the death or resignation of any such Fellow, Member, or Associate, the residue from said payment including the interest thereon, remaining in the said fund, shall be transferred to the general fund of the Institute.*

23. A *Fellow*, Member or Associate who has been dropped as delinquent may be reinstated by the Board of Directors upon payment of all back dues, retaining his original date of

election, and shall be entitled to a complete file of the published TRANSACTIONS corresponding with said payment, provided the same are available.

ARTICLE VI.

ELECTION OF OFFICERS

30. During the first week in February of each year, the Secretary shall mail or deliver to each *Fellow*, Member and Associate of the INSTITUTE, a list of all *Fellows*, Members and Associates, together with a form showing the offices to be filled at the ensuing annual election in May, and containing the names of the incumbents and a copy of sections 30 and 31 of this Article, with the request that nominations be made for the various offices to be filled. These nominations shall not be signed, and shall be enclosed in an envelope, identified on the face by the name of the sender and mailed to the Secretary. To be considered, nominations must reach the Secretary prior to March first. The nomination ballots shall be counted and canvassed by the Committee of Tellers appointed as provided in Sections 34 and 35.

32. The voting for officers shall be restricted to the names of the "Directors' Nominees" and the names on the General Proposal List provided for in section 31 of this Article. This List, together with an envelope on which shall be printed the title of the INSTITUTE, the name and address of the Secretary and the words "Official Voting Envelope—Enclosing a Ballot Only," shall be mailed by the Secretary not later than the first day of April, to every *Fellow*, Member and Associate, together with a copy of sections 32 and 33 of this Article; provided that any qualified *Fellow*, Member or Associate not having a ballot and envelopes shall be entitled to obtain them from the Secretary at any time before the first day of May.

34. The President, at the Directors' meeting to be held in February, shall appoint, subject to the approval of the Board of Directors, five *Fellows*, Members or Associates, not members of the Board of Directors, to constitute the Committee of Tellers; should this Directors' meeting not be held, the President, previous to the twenty-first of February, shall appoint this Committee by letter to the Secretary, who shall notify the members thereof.

35. Any *Fellow*, Member or Associate who shall deliver to the Secretary on or before the first day of March, a written petition signed by at least twenty *Fellows*, Members or Associates, stating their desire that he be a member of the Committee of Tellers, shall also be a member of that Committee; provided that the aforesaid signatures shall not have appeared on another similar petition.

ARTICLE VII

MANAGEMENT. DUTIES OF OFFICERS AND COMMITTEES

46. The Standing Committees to be appointed by the President as specified in section 41 shall be the following:

A Finance Committee of three members.

A Library Committee of five members.

A Meetings and Papers Committee of five members.

An Editing Committee of three members.

A Board of Examiners of five members.

A Sections Committee of five members.

A Standards Committee of nine members.

A Code Committee of seven members.

A Law Committee of five members.

The Board of Directors may appoint auxiliary members to any committee. The members of the Finance Committee shall all be members of the Board of Directors. All other standing committees shall include at least one member of the Board of Directors. All members of the Board of Examiners shall be *Fellows* of the INSTITUTE. All committees shall be directly responsible to the Board of Directors, and shall act under its directions. The Board of Directors may, at any time, at its own discretion, remove any or all members of any committee and appoint others. The terms of the members of all standing and special committees shall terminate at the close of the first meeting of the Board of Directors following the Annual Meeting.

59. The following number shall constitute a quorum of the Board of Directors:

For all business prescribed by statute for a Board of Directors—twelve members or such larger number as the statute may require.

For expulsion of members—fifteen members.

For all other business—five members.

ARTICLE VIII.

MEETINGS

63. Special meetings of the INSTITUTE for the transaction of business may be called by the Board of Directors at any time, by written notice stating the specific object thereof mailed to each *Fellow*, Member and Associate at least thirty (30) days prior to the date of said meeting.

64. Other meetings of the INSTITUTE may be held at such times and places as the Board of Directors shall select, at which no business affecting the organization or policy of the INSTITUTE shall be transacted. Notice of all meetings specified in this Article of the Constitution shall be sent by mail, or otherwise, to all *Fellows*, Members and Associates, at least ten days in advance.

ARTICLE IX.

INSTITUTE SECTIONS AND BRANCHES

65. Whenever, in the judgment of the Board of Directors, a sufficient number of *Fellows*, Members and Associates shall petition, in writing, these members may form, subject to the Constitution and all By-laws, and regulations which may be hereafter prescribed by the Board of Directors a Section organization for the purpose of more effectually carrying out the aims of the INSTITUTE.

66. Any *Fellow*, Member or Associate may become a member of such Section, but a *Fellow*, Member or Associate shall be entitled to vote, or hold office, in one Section only.

67. The officers of each Section shall consist of a Chairman, a Secretary, and such other officers as each Section may find desirable. These officers shall be elected by the votes of the *Fellows*, Members and Associates of that Section, in the manner provided in the Section By-laws. The election of any *Fellow*, Member or Associate as a Section officer, shall not debar him from election or appointment to any other office in the INSTITUTE.

ARTICLE X.

GENERAL

75. A quorum of the INSTITUTE at the Annual Meeting shall consist of not less than five per cent of the total number of *Fellows*, Members and Associates, present in person or by proxy. The same number shall constitute a quorum for the transaction of business at the Annual Convention and at special meetings called as provided in Section 63.

76. Every *Fellow*, Member or Associate entitled to vote at any meeting may so vote by proxy, signed by the *Fellow*, Member or Associate, and filed with the Secretary before the meeting at which it is to be voted. No proxy shall be valid after the expiration of eleven (11) months from the date of its execution, unless the *Fellow*, Member or Associate executing it shall have specified therein the length of time it is to continue in force, which shall be for some limited period. Every proxy shall be revocable at the pleasure of the person executing it.

ARTICLE XI.

AMENDMENTS

79. Amendments to this Constitution may be proposed by means of a petition signed by not less than one

hundred (100) *Fellows*, Members or Associates and received by the Secretary not later than February first; or by means of a Resolution adopted by the Board of Directors not later than February first. Such proposed amendment or amendments shall be submitted to legal counsel by the Board of Directors, and if, in the opinion of such counsel, they are in accordance with the laws under which the INSTITUTE is organized, a copy shall be mailed, with a letter ballot, to each *Fellow*, to each Member and to each Associate, not less than sixty (60) days before the Annual Meeting.

80. Votes, to be considered, shall be received by the Secretary not later than one week before the Annual Meeting. The Secretary shall hand these votes unopened to the Committee of Tellers, which shall count such votes and make a sealed report to the Board of Directors in duplicate, of which one copy shall forthwith be filed with the Secretary, and of which the other copy shall remain in possession of the Chairman of the Committee, who shall hand this report to the presiding officer at the annual meeting. In the absence of this report by the Chairman of the Committee the Secretary shall produce the duplicate copy and hand the same to the presiding officer of the meeting. The presiding officer shall then cause the report to be read. If the total vote be not less than thirty per cent (30%) of the total membership of the INSTITUTE, and if seventy-five per cent (75%) or more of all the *Fellows*, Members and Associates voting shall declare themselves in favor of the proposed amendment or amendments, the same shall become a part of the Constitution.

81. Amendments shall take effect thirty (30) days after their adoption, but officers of the INSTITUTE at the time any amendment becomes effective shall continue in office until the end of the terms for which they were elected.

82. The Secretary shall print copies of the amendments as soon as practicable after adoption, and distribute the same to *Fellows*, Members and Associates.

Designation of "Fellow" Used in Various Societies

Fellow Brit. Ornithologists' Union.
Fellow of Edinburgh Royal Society.
Fellow of City and Guilds of London Institute.
Fellow College of Preceptors.
Fellow of the Chemical Society.
Fellow of the Educational Institute of Scotland.
Fellow of the Entomological Society.
Fellow of the Geological Society.
Fellow of the Institute of Chemisty.
Fellow of the Imperial Institute.
Fellow of the Institute of Journalists.
Fellow of the Linnaean Society.
Fellow of London Geological Society.
Fellow London Society of Letters and Science.
Fellow of Philosophical Society.
Fellow of Philharmonic Society.
Fellow of the Royal Acadamy of Music.
Fellow of the Royal Astronomical Society.
Fellow of the Royal Colonial Institute.
Fellow of the Royal College of Organists
Fellow of the Royal College of Physicians.
Fellow of the Royal College of Surgeons.
Fellow of the Royal Geographical Society.
Fellow of the Royal Historical Society.
Fellow of the Royal Horticultural Society.
Fellow of the Royal Institute of British Architects.
Fellow of the Royal Microscopical Society.
Fellow of the Royal Meteorological Society.
Fellow Royal School Naval Architecture.
Fellow of the Royal Photographic Society.
Fellow of the Royal Society.
Fellow of the Royal Society of Canada.
Fellow of the Royal Society of Edinburgh.
Fellow of the Royal Society of Literature.

Fellow of the Society of Antiquaries.
Fellow of the Society of Antiquaries of Scotland.
Fellow of the Surveyors' Institution.
Fellow of Royal Statistical Society.
Fellow of the Society of Science and Art of London.
Fellow of the Zoological Society.
Fellow of Actuarial Society of America.
Fellow of American Academy of Medicine.
Fellow American Association for the Adv. of Science.
Fellow of the Ethnological Society.
Fellow of the Indiana Academy.
Hon. Fellow Mexican Medical Society.
Hon. Fellow of Franklin Institute.
Hon. Fellow National Geographical Society.
Hon. Fellow Philadelphia Academy of Surgery.
Fellow of the New York Academy of Sciences.
Fellow of the Southern California Academy.
Fellow of Philadelphia College of Physicians.
Fellow of Surgical Association.
Fellow of Texas Academy.
Fellow of American Institute of Architects.

Notes on the Proposed Constitutional Amendments Providing for the Appointment of the Secretary by the Board of Directors

In addition to the amendments to the constitution proposed by the Additional Grade of Membership Committee for a reclassification of the Institute's membership, there will also be submitted for the approval of the members an amendment providing that the Secretary of the Institute shall be appointed by the Board of Directors instead of elected by the membership. This is the same amendment that was presented a year ago and lost because it received a few per cent less than the three-quarter majority necessary to carry it through, and because there was undoubtedly some misunderstanding throughout the membership as to its effect upon Mr. Pope.

Mr. Pope's resignation and his immediate reappointment by the Board of Directors as Honorary Secretary at full salary has removed the possibility of any misunderstanding as to the attitude of the Institute towards the long and valuable services he has so loyally and successfully devoted, and the Board of Directors, therefore, again recommends to the Institute the adoption of the Secretary amendment.

On its merits, the amendment should go as a business proposition. The office of Secretary is one of large responsibilities on which important interests of the Institute depend, and depend in a way that the membership at large cannot as well see or be familiar with as the Board of Directors, who are charged with the detailed conduct of the Institute's business. The Secretaryship ought also to be more or less permanent, and not like the Presidency, which is changed every year by the membership.

The Institute as a whole has full control of its policies through the election of its President and its representatives constituting the Board of Directors, but these very policies might be seriously hampered in the event that a Secretary selected by the membership at large were not the right man for the place, the qualifications of a candidate for which it would be difficult for many of the members to judge. If the Institute should make the office of Secretary elective by the Board instead of elective by the membership, it would be doing no more than is done by the stock-holders in all business corporations even of the greatest magnitude.

The function of a Secretary is not representative, that character residing in the Directors, and it is because the office of Secretary is one involving executive ability and hard work in carrying out the policies of the Board, which are the policies of the members, that it is generally conceded the Board has greater opportunities to judge the suitability of a candidate for Secretary than a large and scattered membership, many of whom may not even know the candidate. The fact that of the votes cast a year ago, although not quite the three-quarter majority required, a large majority were in favor of the amendment, indicates the general sentiment, even at that time.

In view of the removal of the misunderstanding in regard to Mr. Pope, it is expected that the amendment will this year be approved by the requisite three-quarter majority.

On the unanimous recommendation of the committee appointed by the Board of Directors to recommend a Secretary to fill the unexpired term of Mr. Pope, Mr. F. L. Hutchinson, formerly Assistant Secretary, was unanimously appointed. This appointment implies his recommendation to the members for election to the Secretaryship this year, since the amendment that has been above discussed, if passed, will not become effective until next year. The fact that the Board of Directors unanimously appointed Mr. Hutchinson is an indication of their attitude towards the efficiency of his services, and is an example of what the Board would do if, instead of being only an interim appointment, it came before them under authority of the proposed amendment, assuming the latter to be adopted.

The portions of the constitution affected by the Secretary amendment are given below for reference, Italics indicate the parts that are new.

GANO DUNN.

Parts of Constitution Affected by Proposed Secretary Amendment*

ARTICLE V.

OFFICERS

24. The officers of the INSTITUTE shall be a President, six Vice-Presidents, twelve Managers, a Secretary, and a Treasurer, who shall hold office as follows:

25. The President and the Treasurer for one year, the Vice-Presidents for two years, and the Managers for three years. The President, Vice-Presidents and Managers, shall not be eligible for immediate re-election to the same office. A Vice-President shall not be eligible for immediate election to the office of Manager. At each Annual Meeting, the President, three Vice-Presidents, four Managers, and the Treasurer shall be elected in the manner prescribed below, and their terms of office shall commence on the first of August next succeeding their election.

ARTICLE VII

MANAGEMENT. DUTIES OF OFFICERS AND COMMITTEES

37. The affairs of the INSTITUTE shall be managed by a Board of Directors under this Constitution and the general provisions of the laws under which it is incorporated. The Board of Directors shall consist of the President, two Junior Past-Presidents, the Vice-Presidents, the Managers and the Treasurer.

38. The Board of Directors shall have such powers and duties as are prescribed by statute for a Board of Directors.

39. The Board of Directors shall direct the investment and care of the funds of the INSTITUTE, shall make appropriations for specific purposes, shall pass upon all applications for admission or for transfer, shall act upon all questions of expulsion of members,

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*Unchanged parts of present constitution are printed in Roman; changes and additions are printed in Italics.

shall appoint all employees and fix their salaries, and in general shall direct the business of the INSTITUTE, either itself or through its officers and committees.

The Board of Directors at its first meeting in each fiscal year shall appoint a member of any grade to serve as Secretary of the INSTITUTE *for one year, commencing on the first of August next succeeding, subject to removal only by an affirmative vote of a majority of the members of the Board. The Secretary shall receive a salary fixed by the Board. He shall take part in the deliberations of the Board but shall not have a vote therein.*

42. The Secretary shall be the executive officer of the INSTITUTE under the direction of the President and the Board of Directors. He shall attend all meetings of the INSTITUTE and of the Board of Directors, and record the proceedings thereof. He shall collect and deposit, subject to the order of the Treasurer, all moneys due the INSTITUTE, reporting such deposit to the Treasurer, who shall receipt for the same. He shall personally certify the accuracy of bills or vouchers on which money is to be paid, and shall draw and countersign all checks, and these shall be signed by the Treasurer when such drafts are known to him to be proper, and duly authorized by the Finance Committee and in accordance with warrants executed by the Secretary. He shall have charge of the books and accounts of the INSTITUTE. He shall present annually to the Board of Directors a balance sheet, and from time to time shall furnish such statements as may be required. He shall conduct the correspondence of the INSTITUTE, and shall keep full records. He shall be in responsible charge, under the President and the Board of Directors, of all the property of the INSTITUTE. He shall, with the approval of the Board of Directors, employ such clerical force as may be necessary and shall be responsible for the work of all employees of the INSTITUTE. He shall perform such other duties as may be assigned to him. His entire time must be devoted to the affairs of the INSTITUTE, unless otherwise authorized by the Board of Directors.

43. The Treasurer and the Secretary shall invest such funds as may be ordered by the Board of Directors. They shall also pay bills when audited by the Finance Committee and approved by the Board of Directors. The Treasurer shall make an annual report and such other reports as may be prescribed.

44. The Board of Directors may delegate any or all of its powers to an Executive Committee of seven members, consisting of the President and the Treasurer, *ex-officio*, and *five* other members of the Board of Directors, which committee shall conduct the affairs of the Board of Directors between its meetings.

On the Methods of Nominating and Electing Officers in the American Institute of Electrical Engineers.*

By GANO DUNN, PRESIDENT

At the last annual convention of the American Institute of Electrical Engineers, a session was given over to a conference of Institute officers and Section delegates for the purpose of discussing reforms in the methods of nominating and electing officers, so that these might more truly represent the Institute as a whole than it was considered they do at present. A reading of the Proceedings of the session—which have been printed and sent to those taking part—indicates two principal topics of discussion, with divided opinion upon each. They are: 1—whether or not every election shall be a contest, and 2—whether or not a

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*Reprinted by permission from the *Electric Journal*, January 1912.

Member of the Institute, resident outside of New York, has his full voice in the Institute's affairs.

In the writer's opinion, the answer to the first question is a matter of taste. In the politics of our country, from the election of a mayor to that of a president, we are accustomed to contests; and in clean and well-defined contest there is nothing but good health for the state. There are those, however, who feel that in a professional body, in which, relatively speaking, there are no material interests involved and in which an office is solely an honor, different considerations should apply. To these, even a friendly contest over an election appears undignified; their attitude is that an honor should seek the candidate, that the honor is lessened if it be not unanimous, and that one or the other of the candidates must necessarily be placed in the position of seeking the honor if he does not withdraw in favor of his associate.

In the professional and learned bodies of Great Britain and the Continent, contests are practically unknown, and nominations are left in the hands of representative committees, that discuss the merits of various candidates and select one of them, the assumption being that since the nominating committee is provided for in one way or another by the members, the representative men of which it is composed would bring to the selection of candidates the same principles that would govern the members themselves if the selection were general.

Literally speaking, the principle of uncontested elections was adhered to by the American Institute of Electrical Engineers until the last revision of the constitution, when a provision was inserted permitting two members of the Board of Directors to call for a contest. The Institute had gone along on the theory that its Board of Directors, for the election of which every member and associate has a vote, was representative of those members and associates, and, consequently, was a trustworthy nominating committee. Before the last revision of the Constitution, there were only two occasions when its choice of nominees was seriously questioned, and on those occasions its choice was, after all, ratified by the membership.

While the Board of Directors, as a nominating committee, had discretion not to be bound by the nominating votes of the members (these being, according to the Constitution, in the nature of a " straw " vote to give some guidance to the Board), there came to be an unwritten law in respect to the office of President that the candidate receiving the highest nominating vote should be the choice of the Board. When this unwritten law acquired authority, it practically turned the nominating ballot into the electing ballot, and left the Institute without a nominating committee in respect to the Presidency. This drew forth constantly increasing electioneering in favor of various candidates, and at the time of the last revision of the Constitution the unwritten law was transformed into a written one, and it was made practically compulsory upon the Board of Directors to nominate for the Presidency the candidate receiving the highest nominating vote. There was then inserted the provision that, on the request of two members of the Board, a minority candidate should be put upon the Directors' ticket, in order that contests might be permitted. These contests, however, have been only twice called for—the first occasion four or five years ago, when the minority candidate was elected; the second occasion during the last year, when the minority candidate was defeated.

While, by the last revision of the Constitution, the function of the Board of Directors as a nominating committee was taken away in respect to the office of President, it was left in respect to the offices of Vice-President and Manager; in consequence of which the Directors have not always placed in nomination the men whose names have had the highest number of nominating votes. The Board has used its discretion and has occasionally departed from the showing of the list, usally to choose a nonresident candidate, notwithstanding his smaller vote, in preference to a resident candidate with a larger vote; or as between two non-resident candidates, the one who could best represent his constituency by a reasonable attendance at the meetings of the Board.

The provision permitting a contest to be called for in the election of vice-presidents or managers has not been called into use, there never yet having been even two members of the Board who sufficiently disagreed with the choice of the majority as to call for minority nominees.

Coming now to the second question: There is complaint of the preponderating influence of the eastern membership. There is the same complaint in regard to preponderating influence of the eastern states in our national government, with its capital at Washington. The large majority of the memship is in the eastern states, and it is principally in consequence of this that there are more representatives from them on the Board of Directors. It is undoubtedly true that representatives from the Pacific coast, and from the mountain states, have been unusual on the Board of Directors, and when on the Board have been unable to represent their territories by attending meetings. The necessity for attending meetings is very real; and unless a quorum is present the Institute's work is blocked. Unless the Constitution is changed to permit the conduct of the Institute business by correspondence and letter-ballot, the necessity for attendance will continue, and if, as has been suggested, a Constitutional amendment should provide for absentee voting and the conduct of the affairs of the Board by mail, with the control of active affairs left in the hands of an Executive Committee with headquarters at New York, the result would undoubtedly be gradually to take away from the Board as a whole the principal conduct of the Institute's affairs which it now has, and to place it in the hands of the Executive Committee. A reading of the resumes of the work done by the Board of Directors, published in the electrical press after each meeting, will show clearly the very large amount of important business transacted, most of which would gravitate to an Executive Committee if the slow and difficult process of transaction of business by correspondence were introduced. The writer believes that the handling of its business by the whole Board instead of by a small Executive Committee has been one of the sources of the Institute's strength. Such an Executive Committee would of necessity be composed of members who could attend its meetings, and would in turn be open to the charge of not having upon it representatives of the distant constituencies of the Institute. In the writer's opinion, the remedy of letter-voting would satisfy only an ideal and would not be a real remedy.

Some of the Section delegates feel that nomination of officers by delegates would give the distant members greater and more effective representation, a plan having been proposed whereby every seventy-five members were entitled to send one delegate to a nominating convention. It is not clear how this would alter the present situation; in fact, it appears more likely that the plan would reduce the representation of the distant members, since for each group of less than seventy-five members there would be no representation at all. The real difficulty in representation seems to be at present that the membership does not care enough about nominations to vote. Only twenty per-cent of the membership exercises its privilege. And in the case of manager, at the last election this small percentage of the total vote was scattered among 581 candidates, when there were only four candidates to be elected, and the candidate receiving the greatest plurality received only 4.8 per cent of the total vote of the membership. A number of candidates received nearly the same vote, so it is not unreasonable to expect that the Board of Directors, from among so many candidates for nomination, should exercise the discretion vested in it by the Constitution and assist the membership in making selections.

Without attempting at this time to solve the whole problem, the Board of Directors has taken a step in the right direction in an endeavor to secure representative nominations by concentrating upon a few candidates the scattering vote, so that the will of the membership might be more clearly expressed. When nominating ballots have been sent out in the past, there has been nothing to guide the recipient as to who was a suitable person to receive his nomination; but in the future there will accompany the nominating ballots a statement of the names of all nominees in whose favor there has been received at the office of the Secretary of the Institute, prior to January 25th of each year, fifty or more endorsements by petition or individual letter. With the names of these candidates for nomination before a member he is likely to cast his ballot for one of them, and consequently the bulk of the nominating vote, instead of being distributed among over five hundred candidates, will probably be distributed among, say, a dozen, resulting in a clear indication to the Board of Directors of what is the will of the membership.

It is perfectly possible for distant members to band together and concentrate upon a candidate without the method of nomination by delegate, and it would, in fact, be more effective; and is to be hoped that the method of advance nomination by petition, which the Institute has just adopted, will enable distant groups of members to select a man who can attend at least a part of the meetings and to concentrate their votes upon him if they desire to send him as their representative to headquarters.

Secretary of the Institute Appointed

Upon the unanimous recommendation of the Secretary Committee at the meeting of the Board of Directors of the Institute held January 12, 1912, Mr. Frederick L. Hutchinson was unanimously appointed Secretary, from January 1, 1912, to fill the unexpired term of Mr. Ralph W. Pope, who resigned and was appointed Honorary Secretary last summer.

Mr. Hutchinson began his business experience in the service of the Pennsylvania Railroad Company, in one of its principal offices in New York City, where he had several years experience in accounts, correspondence and general office work. In 1889 he entered Cornell University and was graduated from the electrical engineering course in 1893, when he entered the employ of the Westinghouse Electric and Manufacturing Company. After several years' experience in the manufacturing, testing, drafting and sales departments, he entered the publication department, where for a number of years he was employed in preparing the technical literature of the company, including numerous articles for the technical press. In 1901 he became manager of the publication department of the C. W. Hunt Company, and in the following year became advertising manager of the National Electric Company, of Milwaukee. A year later he was made manager of electrical sales for the same company.

In 1904 Mr. Hutchinson returned to New York and undertook some special work on the TRANSACTIONS of the American Institute of Electrical Engineers. Gradually the scope of his work was increased, until in February 1908, upon recommendation of Secretary Ralph W. Pope, he was appointed Assistant Secretary. Upon Secretary Pope's resignation after twenty-six years of service with the Institute, Mr. Hutchinson was, in August 1911, appointed Acting Secretary by the Board of Directors.

Mr. Hutchinson became an Associate of the Institute in 1894. He has served as a member of various Institute committees, and has coöperated with many others. His work during the past few years in connection with the numerous and constantly broadening activities of the Institute has steadily increased. He is thoroughly familiar with the history and policy of the Institute, the scope and duties of its numerous committees and representatives, and the relations of the Institute to other engineering and scientific organizations both in this country and abroad. The impartiality with which he has dealt with all members coupled with the high efficiency he has shown in the discharge of his duties and his very high qualities of character are what led the Board of Directors to select him as worthy to bear the responsibility of the important office of Secretary of the Institute.

Resume of Business Transacted at the Meeting of the Board of Directors of The American Institute of Electrical Engineers, January 12, 1912

The following members of the Board of Directors were present at the meeting held on Friday afternoon, January 12th: President Gano Dunn, New York; Past-presidents Lewis B. Stillwell, New York; D. C. Jackson, Boston, Vice-presidents H. V. Buck and P. H. Thomas, New York; D. B. Rushmore, and C. W. Stone, Schenectady, N. Y.; Managers, A. W. Berresford, Milwaukee, Wis.; H. H. Norris, Ithaca, N. Y.; S. D. Sprong, H. H. Barnes, Jr., W. S. Rugg and Chas. E. Scribner, New York; F. S. Hunting, Fort Wayne, Ind.; Norman W. Storer, Pittsburgh, Pa.; Farley Osgood, Newark, N. J.; and Acting Secretary F. L. Hutchinson, New York.

The new by-law some time ago recommended by the Public Policy Committee to define the status of Sections of the Institute with reference to the expressing of opinions or the issuing of communications that might be construed to represent the Institute as a whole, was adopted; it reads:

> The principal work of a Section shall be the holding of regular meetings for the presentation and discussion of papers on matters relating to electricity, and to the allied arts and sciences, but no action which may purport to represent the policy or organization of the Institute, or of any Section, shall be published or communicated to any party or parties who are not members of the Institute, without the approval of the Board of Directors.

On the recommendation of the Sections Committee, authority was granted in response to the petition of members in Indianapolis and nearby towns of Indiana, to establish an Indianapolis-Lafayette Section.

The programs for the special high tension meeting in New York on March 8th, and the special railway meeting on April 5th, were reported to contain so much in the way of important papers and discussions that on request of the committees in charge of these meetings, and with the approval of the Meetings and Papers Committee, the Board of Directors authorized afternoon sessions commencing at half past four as well as evening sessions on both of the above dates, and, to avoid conflict with these afternoon meetings arranged to advance the hour of its own meetings to half past two preceding them by a directors' luncheon in one of the private dining rooms of the Engineers' Club to give opportunity for preliminary discussion of the large amount of business that is expected to come before these particular meetings.

Upon request of the Schenectady Section, a general Institute meeting to be held at Schenectady early in May on a date to be determined later by the Meetings and Papers Committee, was authorized.

The amendments to the Constitution previously adopted at the December directors' meeting were, after receiving certain modifications, finally adopted by the unanimous vote of the Board for submission in due course to the vote of the membership. Great interest is attached to these amendments not only among technical societies and learned bodies in this country, but abroad.

The Institute has long been in a somewhat anomalous position in having only 10 per cent of its membership in the grade of Member, while 90 per cent of its membership, although consisting very largely of professional electrical engineers, has been in the grade of Associate. For four successive years an attempt has been made to correct this condition by establishing an additional grade of membership in which would find a place that part of the present Associate membership that is professional and technical and equipped with a certain degree of experience, leaving for the grade of Associate that part of the membership which is not equipped with this experience and for which the present qualifications prescribed in the Constitution are, to quote from the Constitution, " a person not less than 21 years of age who is interested in or connected with the study or application of electricity," qualifications intended to be broad enough to include large numbers of non-professional members and others who, although professional, have only begun their experience. The demand for a reformation of the classification of membership has been constant and growing with the growth of the Institute and has merely been following the precedent in the other great engineering and technical societies of this country and Great Britain all of which already have more than two grades.

The successive committees on additional grade of membership appointed during the past four years have carefully studied the question and the present amendments are the result of their successive labors. So difficult was the question of what name to give the new grade, and so great was the confusion among some of the names proposed and some of the corresponding names in other societies, where the terms Member, Associate, Associate Member, become confused and dependent for their significance upon whether they are written with a capital or a small letter, that the committee decided to follow the precedent of the American Institute of Architects, the American Association for the Advancement of Science, and several other important American societies, in addition to the precedent set by a large number of British societies, and to employ the designation " Fellow " for the highest grade. This is to be accompanied by the designation " Member " for the normal grade, and by the designation " Associate " for the general grade.

Having three grades gives opportunity for increasing the standard of the highest grade, which, with the present two grades, has been impossible without doing injustice to many members whose training and professional attainments entitle them to rank in some other grade than that of Associate. This increase of standard for the highest grade is made in the requirement of ten years experience, where formerly five years experience was all that was necessary, and along with the increased length of experience goes an increase of dues and of life membership fees.

The grade of Member retains the requirement of five years experience, but does not insist on the former length of time required for responsible charge of work, provided the member is qualified to take such responsibility. The dues for this grade of membership, to which would probably be transferred a large portion of the present grade of Associate, remain unchanged, as do also the dues for and the qualifications for the grade of Associate.

No distinction is made between Associates, Members, and Fellows in the right to vote, each casting one ballot as formerly.

The Board of Directors instructed the President over its name to send to all the members a letter explanatory of the details of the new arrangement.

Upon the unanimous recommendation of the Secretary Committee consisting of Mr. H. W. Buck, chairman, Mr. W. S. Rugg, Mr. J. J. Carty, and the President, Mr. Frederick L. Hutchinson, for many years Assistant Secretary, and serving as Acting Secretary since the resignation of Mr. Pope on July 1st, was unanimously appointed Secretary to fill Mr. Pope's unexpired term, and the Board in addition to this instructed that the attention of the members of the Institute be called to the provision of the Constitution whereby when a successor has been appointed by the Board of Directors to fill a vacancy, such succession or appointment by the Board of Directors shall not render an officer ineligible for immediate election to the same office.

The Board confirmed its action of a month ago in unanimously adopting another amendment to the Constitution providing for the appointment of the Secretary by the Board instead of his election by the membership, which amendment will be presented to the membership for its consideration at the same time as the amendment above referred to providing for an additional grade of membership.

In accordance with the provision of the Constitution by which Honorary Members may be chosen from among those who have rendered acknowledged eminent service to electrical engineering, or its allied sciences, provided they are proposed by ten members and elected by the unanimous vote in writing of all the members of the Board of Directors, Prof. Andre Blondel, of Paris, France; Mr. C. E. L. Brown, of Baden, Switzerland; Dr. Emil Budde, of Berlin, Germany; Mr. Sebastian Ziana de Ferranti, of London, England, and Professor Antonio Pacinotti, of Pisa, Italy, were elected Honorary Members. These are the first names to receive the distinction of honorary membership since 1892. They were proposed by Messrs. L. A. Ferguson, A. E. Kennelly, John W. Lieb, Jr., C. O. Mailloux, Samuel Sheldon, Henry G. Stott, Elihu Thomson, W. D. Weaver, Schuyler Skaats Wheeler, and James Gilbert White.

The Edison Medal Committee announced that by the unanimous vote of all of its members, it had awarded on December 15, 1911, the gold Edison Medal to Mr. George Westinghouse, "for meritorious achievement in connection with the development of the alternating current system for light and power."

The President announced the appointment of the following new Institute committee on electrophysics authorized by the Board of Directors for developing the study of, and dissemination of information in connection with, electrophysics in view of the important bearing of atomic phenomena upon practical electrical engineering:

Messrs. E. B. Rosa, chairman, E. P. Hyde, Malcolm MacLaren, Edw. L. Nichols, Harold Pender, M. I. Pupin, Harris J. Ryan, Samuel Sheldon, Charles P. Steinmetz, John B. Whitehead, F. A. Wolff.

Chairman Buck of the Meetings and Papers Committee announced the following reception committee for the New York smokers:

H. H. Barnes, Jr., chairman J. R. C. Armstrong, F. C. Bates, Maurice Coster, W. G. Carlton, B. Gherardi, F. V. Henshaw, A. H. Lawton, O. S. Lyford, Jr., A. S. McAllister, W. E. McCoy, C. O. Mailloux, W. S. Murray, Farley Osgood, A. Henry Pikler, Samuel Reber, George F. Sever, H. G. Stott, S. D. Sprong, Samuel Sheldon, W. H. Sawyer, W. I. Slichter, P. H. Thomas, H. S. Putnam.

The vacancy on the Board of Trustees of the United Engineering Society due to the expiration of the term of Past President Louis A. Ferguson, was, by the election of the Board, filled by President Dunn.

With resolutions of regret and particular appreciation of services rendered, the Board accepted the resignation of Mr. Henry G. Stott from the chairmanship of the Public Policy Committee, and from membership on the Code of Ethics, Law, and Indexing Transactions committees, also on the joint Conference Committee of the National Engineering Societies, and his trusteeship in the United Engineering Society.

The President announced the appointment of Mr. J. J. Carty as chairman of the Public Policy Committee, vice-president Mr. H. G. Stott, resigned, and Mr. Paul N. Nunn as a member of this committee; the appointment of Mr. J. J. Carty, and Mr. Calvert Townley, as members of the joint Conference Committee of the National Engineering Societies; also the appointment of Messrs. Clifton V. Edwards and A. S. McAllister as members of the Law Committee.

It having been brought to the attention of the Board that Dr. Alexander C. Humphreys, President of the American Society of Mechanical Engineers, was to accompany the American Institute of Electrical Engineers on its visit to the Isthmus of Panama, a resolution was passed recognizing the presence of the President of our sister society, and extending to him a hearty welcome and the courtesy of an invitation to preside over one of the meetings of the Institute at Panama.

Professor George F. Sever was designated as the official head of the American Institute of Electrical Engineers on the trip to Panama, and it was ordered that he be provided with proper credentials authorizing him to represent the Institute in official relations and ceremonies.

The President was authorized to appoint with the approval of Chairman Charters of the San Francisco Section, Messrs, H. A. Lardner, Chairman S. J. Lisberger, and George R. Murphy, a special conference committee to attend the conference of representatives of the national engineering societies and local societies at San Francisco on January 15 to take steps to organize a general engineering congress to be held during the early part of the summer of 1915, and instructions were given to the committee that while the Institute, on account of the terms under which it was authorized by the International Electrotechnical Commission and the International Electrical Congress of Turin to hold an international electrical congress in September at San Francisco in 1915, was not able to consider the combining of the general engineering congress with the electrical congress, it desired to participate in the general engineering congress as it had done in St. Louis in 1904, and to support in every way the interests of the exposition and of the Pacific coast members.

Professor Edward L. Nichols of the Ithaca Section, and Professors A. E. Kennelly and C. A. Adams of the Boston Section, called the attention of the Board to the fact that the present by-laws excluded from enrolment as students in the Institute numbers of students at their respective universities who are pursuing post-graduate courses, on which the Board provisionally adopted subject to confirmation at the next meeting a by-law removing the limitation at present restricting student enrolment to undergraduate students.

Eighty-six applicants for Associate membership in the Institute were elected. Seventy students were enrolled. Mr. Frederick K. Vreeland was transferred from the grade of Associate to that of Member.

Monthly bills amounting to $8,940.52 were approved for payment.

Panama Trip

The Institute delegation to Panama sailing from New York departed at noon January 17th, on the steamer "Almirante," the party consisting of 59 members and guests. Among the members who were on the pier to bid bon voyage to the party were President Dunn, Honorary Secretary Pope, Secretary Hutchinson, Mr. John H. Finney, Mr. C. O. Mailloux and Mr. S. D. Sprong, to whose efforts the under taking of the trip and the success of the arrangements are due.

The New Orleans party, consisting of 38 members and guests, sailed on the steamer "Cartago" on January 20th, at 4:00 P. M. President Dunn telegraphed his good wishes to the party through Mr. Charles E. Waddell, the representative of the Panama Trip Committee sailing from New Orleans. Ideal weather favored both parties at the start.

The Board of Directors appointed Mr. George F. Sever the official head of the delegation in place of Mr. Severn D. Sprong, who was unable to go.

Through the courtesy of Colonel George W. Goethals, Chairman and Chief Engineer of the Isthmian Canal Commission, a complete program has been arranged for the entertainment of the party while at the Isthmus, including daily inspection trips to different parts of the Canal, a reception by the Tivoli Club at the Hotel Tivoli, and other courtesies. There are fifteen members of the Institute located on the Isthmus, who will meet the delegation on arrival and assist in making the visit profitable and enjoyable.

The New Orleans party is due to arrive on the return trip on February 6th, at 6:00 A. M., the New York party returning on February 8th, at 2:00 P. M. A report of the trip will be published in a later issue of the PROCEEDINGS.

Nomination Petitions

The plan of making preliminary nominations by petition, for the various INSTITUTE offices to be filled at the coming annual election, which was published in detail in the January PROCEEDINGS, has resulted in the preliminary nomination of a number of names. The complete list of candidates for the formal nomination endorsed by fifty or more Members or Associates as provided in Section 18 of the By laws is as follows:

For President:
Ralph D. Mershon, New York, N. Y.

For Vice-Presidents:
A. W. Berresford, Milwaukee, Wis.
H. E. Clifford, Cambridge, Mass.
William S. Murray, New Haven, Ct.
Henry H. Norris, Ithaca, N. Y.

For Managers:
Comfort A. Adams, Cambridge, Mass.
Frederick Bedell, Ithaca, N. Y.
Ernst J. Berg, Urbana, Ill.
William B. Jackson, Chicago, Ill.
S. M. Kintner, Pittsburgh, Pa.
William McClellan, New York, N. Y.
H. St. Clair Putnam, New York, N.Y.
Lewis T. Robinson, Schenectady, N.Y.
J. Franklin Stevens, Philadelphia, Pa.

For Secretary:
F. L. Hutchinson, New York, N. Y.

These names will therefore be published, as candidates for nomination, upon the official nomination forms which will be mailed to all Members and Associates early in February.

Addresses Wanted

Name	Former address
C. F. Boldman,	Ironton, Ohio.
Geo. A. Gabriel,	1064 E. 19th St., Brooklyn, N. Y.
E. G. Gallagher,	St. Petersburg, Rus.
J. R. Klippelt,	Kirksville, Mo.
R. C. Norman,	Lockport, Ill.
E. J. Simon,	230 Riverside Drive, New York City.
Peter V. Schupp,	Minneapolis, Minn.
James P. Starrett,	Lynn, Mass.
J. S. VanBylevelt,	Dresden, Germany.

Members or Associates who can give information that may assist in obtaining any of these addresses are requested to communicate with the Secretary of the Institute.

Standards Committee

The Standards Committee is undertaking a complete revision of the Standardization Rules. Members and Associates who have any suggestions as to additions, modifications or changes in general arrangement, are requested to send them as promptly as convenient to the Secretary of the Committee, Professor C. A. Adams, Pierce Hall, Harvard University, Cambridge, Mass.

Associates Elected January 12, 1912

Auty, Karl André, Chief Illuminating and Power Engineer, British Columbia Elec. Ry. Co.; res., 1193 Pender St. West, Vancouver, B. C.

Bardell, Paul Henry, Power Plant Designer, Sargent & Lundy, 1720 Railway Exchange Bldg.; res., 1536 La Salle Ave., Chicago, Ill.

Barnum, Ward, Electrical Engineer, Louisville & Nashville Railroad Co.; res., 720 West Chestnut St., Louisville, Ky.

Baruch, Milton, Electrical Engineer, Llewellyn Iron Works; res., 2058 Howard Blvd., Los Angeles, Cal.

Bauer, William Charles, Professor of Electrical Engineering, Northwestern University; res., 2149 Sherman Ave., Evanston, Ill.

Beatty, James Hillyard, Canadian General Electric Co., Toronto, Ont.

Beckjord, Walter Clarence, Industrial Fuel Engineer, St. Paul Gas Light Co.; res., 788 Osceola Ave., St. Paul, Minn.

Bradley, John Clement, Assistant Metallurgist, American Brass Co., Waterbury, Conn.

Brinton, Howard Gilbert, Electrical Engineer, General Electric Co., Schenectady, N. Y.

Brodie, John Mollison, Assistant, Transformer Engg. Dept., General Electric Co.; res., 19 Park St., West Lynn, Mass.

Brown, Newton Henry, Professor of Electrical Engineering, University of Texas; res., 2411 San Antonio St., Austin, Texas.

Buchanan, Edward Victor, City Electrical Engineer; res., 594 Talbot St., London, Ont.

Channell, Edgar Cecil, Chief Operator, Power Station, Jhelum Power Installation, Mohora, Kashmir, India.

Cloke, Paul, Assistant Professor of Electrical Engineering, Rhode Island State College, Kingston, R. I.

Collins, Arthur Lee, Duryea, Haehl & Gelman, 1315 Humboldt Bank Bldg., San Francisco, Cal.

Crane, Grauley Stewart, Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 510 Cudahy Apartments, Milwaukee, Wis.

Crawford, James Marion, Chief Electrician Winslow Electric Light & Power Co., Winslow, Ariz.

Dawson, Benjamin, Electrician, Cedar Rapids & Marion City Railway Co.; res., 1712 E Avenue, Cedar Rapids, Ia.

Drew, John Laurence, Philadelphia Electric Co.; res., 1428 Catharine St., Philadelphia, Pa.

Duddell, William Du Bois, Consulting Engineer, 56 Victoria St., Westminster; res., 47 Hans Place, London, S. W., Eng.

Eberhart, Maximilian, Joseph, Engineering Assistant, Public Service Electric Co.; res., 1007 S. Broad St., Newark, N. J.

Eidson, Charles George, Professor of Mechanical Engineering, St. John's College, University of Maryland, Annapolis, Md.

Estill, David Chenault, Designing Engineer, General Electric Co.; res., 966 State St., Schenectady, N. Y.

Fellenberg, Wilhelm, G. O. A., Consulting Engineer, H. Schoenberg & Sohm Actien Gesellschaft, Berlin-Charlottenburg, Germany.

Finsen, Eyvind, Draughtsman, Toronto Power Co., Niagara Falls, Ont.

Forbes, Allan White, Engineering Department, Crocker-Wheeler Co., Ampere; res., 122 N. 17th St., East Orange, N. J.

Forst, Adolf, Electrical Engineer, Dietz Company, 60 Laight St.; res., 1011 East 178th St., New York, N. Y.

Fox, Charles Adin, Great Western Power Co., Shreve Bldg., San Francisco, Cal.

Gary, Laurence Albert, Telephone Engineer, Rooms 214-216, 702 S. Spring St.; res., 928 W. 6th St., Los Angeles, Cal.

Gentis, R., Albert, Foreman, Operation & Maintenance Dept., Pacific Gas & Electric Co.; res., 19th & Telegraph Ave., Oakland, Cal.

Gilmore, Frank Lansing, General Superintendent, Guanajuato Power & Elec. Co., Apartado 50, Guanajuato, Mex.

Harding, Percy Hugo, Construction Engineer, Guanajuato Power & Electric Co., Apartado 50, Guanajuato, Mex.

Harrelson, Allen McRae, Engineer, Emerson Electric Mfg. Co., 2030 Washington Ave.; res., 5748 McPherson Ave., St. Louis, Mo.

Harrison, William, Jr., Salesman, Canadian Westinghouse Co., Ltd., Bank of Ottawa Bldg.; res., 1636 Barclay St., Vancouver, B. C.

Hutchins, Frank Adalyn, Electrical Engineer, General Electric Co., West Lynn; res., 52 Redington St., Swampscott, Mass.

Israel, Lewis Walter, Switchboard Operator, Philadelphia Electric Co.; res., 3222 Ridge Ave., Phila., Pa.

Jansen, Hector Hubert, Electrical Supt., Boustead Brothers, Pettah, Colombo, Ceylon.

Jordan, Francis James, Power Engineer, British Columbia Electric Ry. Co., Ltd., Vancouver, B. C.

Karino, Yoshio, Electrical Engineer, Electrical Dept., Imperial Government Railways, Toyko, Japan.

Kneeland, Ralph Pratt, Inspector, Department Lines & Bonding, Bay State Street Railway Co., 333 Union St.; Res., 2 Rogers Ave., Lynn, Mass.

Knowlton, Howard Sprague, Technical Correspondent, 23 Richardson St., Newton, Mass.

Lawrence, Edward Fred, Electrical Engineer, Siemens-Schuckert-Werke, Askanischer Platz, 13 Born St., Berlin, Fridenau, Germany.

Leahey, Edward Francis, Electrician, Los Angeles Aqueduct, Lone Pine, Cal.

Lehmann, Emil Wilhelm, Instructor in Physics, Texas Agricultural & Mechanical College, College Station, Texas.

Lehuraux, Louis, Designing Engineer, General Electric Co.; res., 1202 Union St., Schenectady, N. Y.

Leitch, George Alexander, Engineer in charge of electrification, Central Argentine Railway, Buenos Aires, A. R.

Lenker, Leslie Emerick, Student, University of Arkansas; res. 614 Ida Ave., Fayettville, Ark.

Lennox, John Seymour, Electrical Engineer, General Electric Co.; res., 49 Hull Ave., Pittsfield, Mass.

Loubet, Louis Manuel, Student Engineer, General Electric Co.; res., 104 So. Church St., Schenectady, N. Y.

McCulloch, Robert London, Electrical Engineer, Matsqui Sub-station, British Columbia Electric Railway Co., Matsqui, B. C.

McGovern, Maurice Terrance, Student Apprentice, General Electric Co.: res., 76 Plunkett St., Pittsfield, Mass.

Merchant, Claude John, Director of Industrial Training, Public Schools; res., 14 Orange St., Waverly, N. Y.

Merck, William Emory, Superintendent, City Water and Light Plant; res., South Main St., Easley, S. C.

Moffitt, Harry Alonzo, Assistant General Supervisor of Traffic, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.

Murphy, Frederick Thomas, Salesman, Electric Installation Co.; res., 713 No. Howard St, Baltimore, Md.

Myers, Florian Dwight, Engineer, Construction Dept., Fort Wayne Electric Works; res., 2413 S. Harrison St., Fort Wayne, Ind.

Nivling, Harrison, Salesman, Cutler-Hammer Mfg. Co. Room 1002 N. Y. Times Bldg.; res., 1918 82nd St. Brooklyn, N. Y.

Peters, John William, Patent Lawyer and Expert, 52 William St.; res., 501 W. 140th St., New York, N. Y.

Rice, Louis Nelson, Electrical Department, Spokane & Inland Empire R. R. Co.; res., 1403 12th Ave., Spokane, Wash.

ROBINSON, LUKE, Manager Insulating Department, Standard Varnish Wks., 29 Broadway, New York, N. Y.; res., 10 Bursley Pl., White Plains, N. Y.

RÖESEN, OSCAR CHARLES, Student, Stevens Institute of Technology, Hoboken, N. J.; res., 558 Decatur St., Brooklyn, N. Y.

ROSCOE, EDWIN BORTON, Electrical Engineer, Traction Dept., Buenos Aires Western Ry., Buenos Aires, A.R.

ROSE, CLARENCE EDWARD, Vice-President & Manager, Arkansas Cold Storage Co.; res., 500 East 6th St., Little Rock, Ark.

ROWLAND, ERNEST WILSON, Chief Bond Inspector, Public Service Railway Co., Newark; res., 138 S. Grove St., East Orange, N. J.

SHAND, JOHN ALBERT, Sales Engineer, Allis-Chalmers-Bullock, Ltd., 814 Dominion Trust Bldg., Vancouver, B.C.

SHANKS, DANIEL ALBERT, Allis-Chalmers-Bullock, Ltd.; res., 716 Dorchester St., West, Montreal, Que.

SKIRM, GEORGE LOUIS, Construction Engineer, Allis-Chalmers-Bullock, Ltd., Montreal, Que.

SMALLEY, DEAN FRED, General Electric Co.; res., 114 Jenness St., Lynn, Mass.

SMERLING, DANIEL, Mercury Arc Rectifier Expert, General Electric Co., Lynn; res., 52 Redington St., Swampscott, Mass.

SMITH, ERIC WILBURN, Foreman Induction Motor Test, General Electric Co.; res., 11 Congress St., Lynn, Mass.

SPALDING, HENRY KENARIC, Manager, Aluminum Company of America, 99 John St.; res., 36 Washington Sq., West, New York, N. Y.

STEVENSON, GEORGE HERBERT, Engineer, Western Electric Co., 463 West St.; res., 41 East 22nd St., New York, N. Y.

STRUNK, WALTER CYRUS, Electrical Department, Metropolitan St. Ry. Co.; res., 111 W. 49th St., New York, N. Y.

TAYLOR, WALTER BRONSON, Standardizing Laboratory, General Elec. Co., Schenectady; res., Scotia, N. Y.

TYLER, HAVEN GREELEY, Assistant in Mechanical Engineering, Polytechnic Institute of Brooklyn; res., 102 Macon St., Brooklyn, N. Y.

VALK, EUGENE ERIC., Engineering Dept., General Electric Co.; res., 27 Front St., Schenectady, N. Y.

WALKER, ALBERT STUART, Electrical Engineer, General Electric Co.; res., 7 Arlington St., Lynn, Mass.

WALTER, IRA H., Chief Electrician, Montreal Locomotive Works, Ltd.; res., 31 3rd Ave., Maisonneuve, Que.

WEST, JOHN W., Electrical Engineer, General Electric Co., Lynn; res., 15 Mall St., West Lynn, Mass.

WESTCOTT, BAYSE NEWCOMB, Electrical Engineer, Power and Mining Dept., General Electric Co.; res., 124 Lafayette St., Schenectady, N. Y.

WEXLER, LEON I., Electrical Draftsman, General Electric Co.; res., 328 Paige St., Schenectady, N. Y.

WILSON, JOSEPH HENRY, Superintendent, Electrical Dept., American Rolling Mill Co.; res., 708 Baltimore St., Middletown, O.

WOLF, MAURICE ARTHUR, Draughtsman, Edison Storage Battery Co., West Orange; res., 253 Belmont Ave., Newark, N. J.

WOODCOCK, FREDERICK, Manager, Mexican Telegraph Co.; res., 2a Pte de Alvarado 45, Mexico, D. F.

WOODROW, HARRY ROY, Assistant to Chief Electrical Engineer, New York Edison Co., 55 Duane St.; res., 257 W. 129th St., New York, N. Y.

ZEBLEY, JUNE SILAS, Electrical Construction Estimator, National Electrical Supply Co., 1330 New York Ave., Washington, D. C.

Total 86.

Associates Transferred on January 12, 1912

FREDERICK K. VREELAND, Experimental, Research and Consulting Expert Work, 80th Street and East End Avenue, New York.

Recommended for Transfer

The following Associates were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on January 9, 1912. Any objection to the transfer of these Associates should be filed at once with the Secretary:

Herbert R. Harper, City Electrical Engineer, Municipality of Melbourne, Australia.

Edward H. Everitt, Chief Engineer, Southern New England Telephone Co., New Haven, Conn.

Frederick W. Ells, Secretary and Engineer, Northwestern Manufacturing Company, Milwaukee, Wis.

L. A. Osborne, Vice-President, W. E. and M. Company, Pittsburgh, Pa.

Nicholas Stahl, Commercial Engineer, W. E. and M. Company, Pittsburgh, Pa.

Nathan Hayward, Chief Engineer, Bell Telephone Company of Penn., Philadelphia, Pa.

George L. Hoxie, Consulting Engineer, 50 Church Street, New York.

Clayton H. Sharp, Test Officer, Electrical Testing Laboratories, 80th Street and East End Avenue, New York.

Alexander C. Humphreys, President, Stevens Institute of Technology, Hoboken, N. J.

Carl J. Fechheimer, Electrical Engineer, Crocker-Wheeler Company, Ampere, N. J.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Acting Secretary before February 24, 1912.

10996 Andrews, J. H. M., Phila., Pa.
10997 Barber, R. H., Chicago, Ill.
10998 Benedict, A. I., Chicago, Ill.
10999 Bradley, C. L., Visalia, Cal.
11000 Branson, W. J., Pittsburgh, Pa.
11001 Burnham, W. A., Chicago, Ill.
11002 Chapman, A. K., Seattle, Wash.
11003 Clerke, D. D., Kansas City, Mo.
11004 Cromwell, L. W., Havana, Cuba.
11005 Cundell, A. B., W. Lynn, Mass.
11006 Dawes, C. L., Cambridge, Mass.
11007 Dean, H. C., Chicago, Ill.
11008 Dorzeski, V. A., Chicago, Ill.
11009 Emery, F. O., Madison, Wis.
11010 Feller, C. V., Schenectady, N. Y.
11011 Fingado, R. T., Mexico, D. F.
11012 Fischer, H. F., Berkeley, Cal.
11013 Fleet, A. H., Milwaukee, Wis.
11014 Fleming, R. F., Harrison, N. J.
11015 Fried, J. A., Ithaca, N. Y.
11016 Godfrey, F. O., Chicago, Ill.
11017 Goldmerstein, L., New York, N.Y.
11018 Gray, G. H., Provo, Utah.
11019 Green, H. V., Schenectady, N.Y.
11020 Hart, R. A., Salt Lake City, Utah.
11021 Highland, C., Niagara Falls, N.Y.
11022 Hoge, J. C., Lincoln, Neb.
11023 Holmes, J. D., Pasadena, Cal.
11024 Hooper, W. E., Mexico, D. F.
11025 Hopkins, M. L., St. Louis, Mo.
11026 Houghton, A. J., Jr., Coronado, Cal.
11027 Humphreys, A. C., New York, N.Y.
11028 Hutson, M. B., New Orleans, La.
11029 Jacoby, L., Houston, Texas.
11030 Johnson, C. O., Jamestown, N.Y.
11031 Jones, B. H., New York, N. Y.
11032 Katsuno, S., Kansas City, Mo.
11033 Kilner, R. H., Chicago, Ill.
11034 Kirkpatrick, J. G., Ashland, Ore.
11035 Kite, J. M., Albany, N. Y.
11036 Krausnick, W. S., St. Louis, Mo.
11037 Lane, H. S., Berkeley, Cal.
11038 Lyon R. R., Fort Terry, N. Y.
11039 Mattison, W.D., New York, N.Y.
11040 May, R. B., Cincinnati, Ohio.
11041 Mills, J. L., Chicago, Ill.
11042 Moser, G., Anaconda, Mont.
11043 Pierce, P. H., New York, N. Y.
11044 Piper, F. S., Manchester, N. H.
11045 Plimpton, R. E., W. Lynn, Mass.
11046 Roberts, W. J., Cincinnati, Ohio.
11047 Rose, H., Chicago, Ill.
11048 Salkeld, A. S., Schenectady, N.Y.
11049 Sharp, A. W., Jr., Chicago, Ill.
11050 Shearer, H. A., Portland, Ore.
11051 Shiperk, A., Seattle, Wash.
11052 Stevenson, R. L., Ithaca, N. Y.

11053 Stringfellow, H. M., Mexico City, Mex.
11054 Tassie, R. W., Havana, Cuba.
11055 Thayer, E. S., Portland, Ore.
11056 Thayer, H. S., Chicago, Ill.
11057 Thorp, T. A., Boston, Mass.
11058 Unland, H. L., Schenectady, N. Y.
11059 Waldmann, C. A., Portland, Ore.
11060 Whitehurst, R. F., Jr., Oakland, Cal
11061 Durgin, W. A., Chicago, Ill.
11062 Lent, W. F., Passaic, N. J.
11063 Finch, J. W., Los Angeles, Cal.
11064 Schooley, C. O., Pittsburgh, Pa.
11065 Nietz, L. C., Philadelphia, Pa.
11066 McKenzie, L. F., Detroit, Mich.
11067 Rylander, J. L., Irwin, Pa.
11068 Fulton, H. H., Concord, Cal.
11069 Hoyt, J. C., Winnipeg, Man.
11070 Anderson, B., Portland, Ore.
11071 Willard, L. L., Uniontown, Pa.
11072 Janney, J. A., Jr., New York, N. Y.
11073 Mode, H. L., Lynn, Mass.
11074 Zimmerman, P. C., Yamhill, Ore.
11075 Wyman, F. T., Pittsburgh, Pa.
11076 Wright, G. R., Vancouver, B. C.
11077 Morin, J. H., Schenectady, N. Y.
11078 Shackelton, W. J., New York, N. Y.
11079 Wright, J. C., New York, N. Y.
11080 Marriner, A. W., Chicago, Ill.
11081 Alling, S., Rochester, N. Y.
11082 Altamirano, S. E., Mexico, D. F.
11083 Small, F. F., Los Angeles, Cal.
11084 Stevens, F. W., New Orleans, La.
11085 Jacobs, G. S., San Francisco, Cal.
11086 Buchan, P. H., Vancouver, B. C.
11087 Bucks, H. R., Salt Lake City, Utah.
11088 Carter, F. E., Holtwood, Pa.
11089 Chase, P. H., Newark, N. J.
11090 Dempsey, W. T., New York, N. Y.
11091 Duncan, G. M., Little Rock, Ark.
11092 Hull, S. W., New York, N. Y.
11093 Eddy, L. C., New York, N. Y.
11094 Pendergast, R. B., Boston, Mass.
11095 Stone, C. G., Jr., Mt. Vernon, N. Y.
11096 Wulsin, L. Jr., Boston, Mass.
11097 Foltz, L. S., Springfield, Ill.
11098 Mulrony, M. A., Sydney, Aus.
11099 Limon, G., Orizaba, Mex.
11100 Bacon, J. L., Jr., Pawtucket, R. I.
11101 Giles, R. E., Peabody, Mass.
11102 Snodgrass, C. C., Sisterville, W. Va.
11103 Wilson, R. G., Humboldt, Iowa.
11104 Still, A., Sault Ste. Marie, Ont.
11105 Gillon, G., Louvain, Belgium.
11106 Hilton, E. G., E. Liverpool, Ohio.
11107 Axel, S., Chicago, Ill.
11108 Murphy, H. A., Butte, Mont.
11109 Crosby, T. H., Toronto, Ont.
11110 Carlson, C. L., Ruskin, B. C.
11111 Edge, D., Swissvale, Pa.
11112 Smith, G. B., Belleville, Ont.
11113 Sullivan, H. I., Dorchester, Mass.
11114 Milton, I. L., Brooklyn, N. Y.
11115 Growdon, J. P., Estacada, Ore.
11116 Bliss, F. Jr., New York, N. Y.
11117 Larner, C. W., Cleveland, Ohio.
11118 Jones, C. H., Chicago, Ill.
11119 Hatch, E. G., New York, N. Y.

Total, 124.

Students Enrolled January 12, 1912

4840 Schalchlin, G. W., Univ. of Arkansas.
4841 Walter, L., Columbia University.
4842 Cheney, I. L., Washington Univ.
4843 Duncan, R. D., Jr., Wash. Univ.
4844 Lucking, L. L., Washington Univ.
4845 Stiner, H. W., Penn. State College.
4846 Mowry, C. J., Univ of Nebraska.
4847 Montgomery, G. E., Univ. of Neb.
4848 Nevins, W. I., Lehigh University.
4849 Warner, R. A., Michigan Agri. Col.
4851 Raines, H., Stanford University.
4852 Diesser, S. R., Cornell University.
4853 Leslie, G. M., Cornell University.
4854 Mettenet, F. X., Cornell Univ.
4855 Stark, F. E., Cornell University.
4856 Tsuchiya, S., Cornell University.
4857 Nash, J. C., University of Toronto.
4858 Fryburg, W. F., Armour Inst. Tech.
4859 Bugbee, R. L., Tufts College.
4860 Northrop, F. F., Univ. of Oregon.
4861 Washburne, C. B., Univ. of Ore.
4862 Warrick, C. F., Univ. of Michigan.
4863 Brown, H. L., Univ. of Michigan.
4864 Turpin, W. H., Univ. of Michigan.
4865 Duffey, A. J., Univ. of Michigan.
4866 Linker, A., Univ. of Michigan.
4867 Cummings, L. T., Mass. Inst. Tech.
4868 Mills, H. H., Stevens Inst. Tech.
4869 Steck, W. S., Univ. of Toronto.
4870 Graham, E. B., Univ. of Toronto.
4871 Hickling, F. G., Univ. of Toronto.
4872 Story, R. A., Univ. of Toronto.
4873 Nixon, C. K., Univ. of Toronto.
4874 Seaton, N. D., Univ. of Toronto.

4875 Parker, J. S., Univ. of Toronto.
4876 Brown, H. O., Univ. of Toronto.
4877 O'Donnell, V. J., Univ. of Toronto.
4878 McEwen, H. J., Univ. of Toronto.
4879 Moseley, J. H., Univ. of Texas.
4880 Evans, A. A., Univ. of Texas.
4881 Leverence, H., Univ. of Texas.
4882 Aldridge, S. W., Univ. of Texas.
4883 Crawford, M. C., Univ. of Texas.
4884 Lovli, J. W., Univ. of Texas.
4885 Crossley, J. H., Univ. of Texas.
4886 Sticht, A. E. J., Rensselaer Poly. Inst.
4887 Wright, J. E., Univ. of Illinois.
4888 Delvin, R. B., Mich. Agri. Coll.
4889 Lambert, A. W., Jr., Wash. Univ.
4890 Federle, J. C., Univ. of Cincinnati.
4891 Williams, R., Penn. State College.
4892 Gocher, R. M., Penn. State College.
4893 Soengen, G. W., Univ. of Missouri.
4894 Langstaff, H. A. P., Armour I. T.
4895 Stern, K. G., Columbia Univ.
4896 Cook, J. A., Mass. Inst. Tech.
4897 Savant, D. P., Rose Poly. Inst.
4898 Service, J. H., Jr., Rose Poly. Inst.
4899 Kietzmann, W. A., Univ. of Wis.
4900 Mace, W. S., Rose Poly. Inst.
4901 Hoffman, E. L., Armour Inst. Tech.
4902 Bacon, C. A., Tufts College.
4903 Aldworth, E. L., Yale University.
4904 Combes, R. C., Univ. of Michigan.
4905 Steere, F. W., Univ. of Michigan.
4906 Lebensburger, M. A., Univ. of Mich.
4907 Kiehl, E. P., Univ. of Penn.
4908 Yerkes, E. P., Univ. of Penn.
4909 Bicknell, H. I., Tufts College.
4910 Stoddard, F. M., Ohio State Univ.

Total, 70.

Future Section Meetings

TORONTO

The Toronto Section will hold its next regular meeting at the Engineers' Club, Toronto, Ont., on Friday evening, February 2, 1912. A paper will be presented by Mr. F. C. E. Burnett, electrical engineer of the Canada Cement Company, on "Electric Power in Cement Mills." The Canada Cement Company have plants at different points throughout the country, all of which are using electric power, and this should be a particularly interesting meeting.

The March meeting of the Toronto Section will be held on Friday evening, March 1, 1912, at 8 p.m., at the Engineers' Club, Toronto. Mr. Julian C. Smith, general superintendent and chief engineer of the Shawinigan Water and Power Company, will read a paper on "The Shawinigan Power Company's System." This is one of the largest water power developments in the country.

WASHINGTON, D. C.

The February meeting of the Washington Section will be held on Tuesday, February 13. A member of the Public Policy Committee of the Institute will address the Section, the title of the paper and place of meeting to be announced later. H. B. Stabler, 722 12th Street, N. W., Washington, D. C.

Past Section Meetings

BALTIMORE

The Baltimore Section held a banquet on December 15, 1911, at the Hotel Raleigh, Baltimore. Thirty-four members were present. After the banquet Dr. J. B. Whitehead, of the Johns Hopkins University, gave an account of the doings of the International Electrochemical Commission. Mr. C. G. Edwards gave an interesting talk on "Automatic Telephony," with special reference to the automanual system.

BOSTON

The December meeting of the Boston Section was held jointly with the American Society of Mechanical Engineers and the Boston Society of Civil Engineers on December 20, 1911. Mr. W. L. R. Emmet, engineer of the General Electric Company, presented a paper illustrated by lantern slides, on "Electric Propulsion of Ships." Two hundred and forty members of the three societies were present.

A special meeting of the Boston Section was held in Robinson Hall of Tufts College on Saturday evening, January 6. The program included an inspection of the laboratories of the engineering department during the latter part of the afternoon, followed by a dinner which was served in one of the college buildings. The regular meeting was called to order at eight o'clock, and Mr. G. A. Burnham, engineer for the Condit Electric Manufacturing Company, read a paper entitled " The Characteristics of Time Limit Relays."

CHICAGO

The Chicago Section held its regular monthly meeting jointly with the Electrical Section of the Western Society of Engineers on December 27, 1911. A paper on " Protection of High Tension Power Circuits and Apparatus" was presented by Mr. James Lyman.

CLEVELAND

The regular monthly meeting of the Cleveland Section was held in the Chamber of Commerce Library on Monday evening, December 18, 1911. In the absence of Chairman B. A. Stowe, Mr. G. E. Miller presided. Dr. Arthur A. Hamerschlag, director of the Carnegie Technical Schools, Pittsburgh, Pa., addressed the members on the subject, " Engineering Education." The subject was also discussed by Dr. C. S. Howe president of the Case School of Applied Science, Professors H. B. Dates, and J. F. Barker, and Messrs. G. E. Miller, E. P. Roberts, J. C. Lincoln, and A. B. Burk. A number of interesting points were brought out in the course of the discussion, among which were the following: That the college manufactures a product and it should take the necessary steps to see that this product is placed where it is demanded; that the function of the college is not to produce engineers, but to produce men; that one of the best stimulants to the engineering student is not more engineering, but other humanities. Another point brought out in the discussion was that the Institute could greatly assist not only the schools and colleges, but also the profession as a whole, by submitting a carefully selected series of problems to be solved by the students. This plan is now being carried out in certain schools of architecture with very good results.

DETROIT-ANN ARBOR

The regular monthly meeting of the Detroit-Ann Arbor Section was held at the Hotel Tuller, Detroit, on December 16, with Professor C. L. de Muralt presiding, and an attendance of 27 members. A paper on " Commercial Applications of Electric Motors " was presented by Mr. C. D. Noyes, of the Westinghouse Electric and Manufacturing Company.

FORT WAYNE

The Fort Wayne Section held its regular meeting on December 21. Action was taken endorsing the proposed amendment to the Institute Constitution making the office of Secretary appointive by the Board of Directors instead of elective by the membership, also endorsing the proposed amendments creating an additional grade of membership.

The paper of the evening was presented by Mr. P. H. Haselton, which was a review of the G. A. Maier's recent paper entitled " Methods of Varying the Speed of Alternating Current Motors." This paper led to considerable discussion, in which the following members took part: Messrs. A. B. Morrison, E. A. Wagner and F. M. Webber.

LOS ANGELES

The regular monthly meeting of the Los Angeles Section was held at Hamburger's Cafe, Los Angeles, on December 19, 1911, in coöperation with the Engineers and Architects Association. One hundred and thirty-eight members and visitors were present. Mr. Theodore B. Comstock, engineer of the Board of Public Utilities, read a paper on " Evolution versus Revolution in Public Service." Those taking part in the discussion were: Messrs. G. A. Damon, R. H. Ballard, F. H. Olmstead, C. L.

Cory, W. Woodward, O. H. Ensign, and D. S. Halladay. Dr. F. A. Wolff, of the Bureau of Standards, Washington, D. C., was one of the guests at the meeting, and made a few brief remarks.

LYNN

The fourth regular meeting of the Lynn Section was held in Odd Fellows Hall, West Lynn, on December 14, 1911. One hundred and seventy-eight members were present. The membership committee reported that the membership of the Lynn Section to date was as follows: Institute Members and Associates, 75; enrolled students, 13; Local Members in good standing, 304; total, 392. Chairman Boyer made a statement regarding the annual convention of the Institute, which is to be held in Boston next June. Professor Dugald C. Jackson, of Boston, a past-president of the Institute, was then introduced, and gave a lecture on the subject, " The Relation of Electrical Engineering to the Industrial Arts."

MEXICO

A social meeting of the Mexico Section was held at the Salon Bach, City of Mexico, on December 28. A special effort had been made to secure a large attendance, and about fifty members and guests were present. Mr. W. H. Fiske presided. Mr. A. E. Reynolds spoke on the objects and ideals of the Institute. Mr. James Carson spoke on the necessity of organization for engineers. Mr. W B. Hale made some remarks on the relations of the Sections of the A.I.E.E. to the national organization. Messrs. H. C. Hawkins, W. B. Hale and W. N. Parsons were appointed members of the executive committee.

MILWAUKEE

The December meeting of the Milwaukee Section was held in coöperation with the Engineers Society of Milwaukee on December 13, 1911. Mr. Edmund D. Garfield, of Manning, Maxwell and Moore, gave a talk on " Modern Machine Tools," making comparisons of many types of tools of to-day with those of 20 years ago, and pointing out many of the features which have led to the increased production of these modern machine tools. Illustrations of modern tools were shown, and the particular features which give them increased production were described in detail. The discussion of the talk was general and included reminiscences by several members, of improvements in certain specific operations. Notably among these was the reduction in time of turning out a pair of engine driving wheels from four days 20 years ago, to about two hours at the present time. Some instances of need for improved machine tools or details of driving them were suggested and discussed.

Previously to Mr. Garfield's talk, the committee on Milwaukee municipal engineering progress made its first report covering the plan of the city with relation to a new intake for the water works system. The committee plans to report at each meeting some phase or project of the municipal engineering department with the idea of keeping the members of the engineering fraternity posted on municipal affairs of an engineering nature.

PITTSBURGH

The Pittsburgh Section held its regular meeting on December 12, in the auditorium of the Engineers Society of Western Pennsylvania. One hundred and nine members were present. The following papers were presented: " Power Supply to Electric Furnaces," by W. Sylves; " The Electric Furnace," by P. M. Bennie, abstracted by Mr. H. C. Soule; " Commercial Status of the Electric Furnace," by C. B. Gibson. The papers were discussed by Messrs. N. Stahl, H. N. Muller, and W. E. Reed.

The next regular meeting of the Pittsburgh Section was held on January 9. A paper on " Central Station Power in Coal Mines," was read by Mr. W. A. Thomas, and discussed by Messrs.

W. E. Moore, H. C. Spence, and W. B. Bright.

PITTSFIELD

The regular monthly meeting of the Pittsfield Section was held in the Hotel Wendell, Pittsfield, on December 15, 1911. Mr. H. M. Hobart, consulting engineer of the General Electric Company, Schenectady, addressed the members on "Comments on Recent Prospective Developments in Electrical Engineering." Mr. Hobart's remarks covered a wide range of subjects, and his comments on possible and probable developments were interesting. He discussed the subject under the following heads: Steam turbines, induction generators, synchronous generators, Diesel engines, static rectifiers, railway substations, electric traction, isolated plants, ventilating schemes, electric propulsion of ships. The following members took part in the discussion: Messrs. G. Faccioli, J. M. Weed, W. S. Moody, M. T. McGovern, F. C. Green, L. L. Stanley and W. M. Strickler.

The meeting was preceded by a dinner in honor of Mr. Hobart, at the Hotel Wendell, which was attended by 13 engineers.

PORTLAND, ORE.

The Portland Section held its regular monthly meeting in the assembly hall of the Electric Building, Portland, on December 19, 1911. The membership, luncheon and library committees made their reports. The library committee reported that it had interviewed the Board of Trustees of the Library Association in regard to the new library building which is to be built, with the idea of persuading the association to provide facilities for the benefit of the engineering societies and the technical men in the city. It is expected that the Library Association will set aside certain space in the new building for technical works and magazines.

Professor W. A. Hillebrand, of the department of electrical engineering at the Oregon Agricultural College, presented the paper of the evening, entitled "The Problem of Efficiency in Teaching." Professor Hillebrand gave some interesting data in regard to cost of education and how the cost affected the efficiency. It was stated that in order to maintain a satisfactory efficiency, the cost per student hour should not fall below a certain point. Actual costs were given as applied to Professor Hillebrand's department at the Oregon Agricultural College.

SCHENECTADY

The Schenectady Section held its regular meeting in Red Men's Hall on January 2. One hundred and thirty members were present. A paper entitled "Some Proposed Changes in the Patent System" was read by Mr. Albert Gould Davis.

ST. LOUIS

The regular meeting of the St. Louis Section was held on December 20, with a total attendance of about 50 members and guests. This meeting was postponed from the second to the third Wednesday, on account of the annual banquet of the Engineers Club of St. Louis, with which the Section is affiliated.

The speaker was Mr. H. H. Humphrey, who addressed the members on the subject, "The Consulting Electrical Engineer." Mr. Humphrey endeavored to explain in a general way the primary purpose of the consulting engineer and then enlarged upon his various fields of activity. The isolated lighting and power plants form a large field for the work of the consulting engineer. These are confined mostly to our large cities and industrial centers, and are in a sense opposed to the service of the central station. In the opinion of the speaker these must in time give way to the central station, which will assume larger and larger proportions. Finally, the generating stations in different cities will be connected together with a network of high tension conductors so as to help each other in cases of emergency. The Keokuk power transmission scheme was referred to as a case in point, since in case of an accident to its generating plant, the power plant in St. Louis and other cities supplied from this water power plant can be started up and feed back through the transmission lines, and so keep the entire system in operation. The fact that the large central stations are doubling their capacity every four years shows that the need for engineers in this line of work is not likely to be curtailed in the near future. The street railways of our country furnish another large field of endeavor for the consulting electrical engineer, and closely allied to these are the interurban roads, terminals and tunnels of steam roads, and the short branches or feeders for the great trunk lines of the country. Mr. Humphrey called attention to the great possibilities in water power development in this country as shown by the fact that only 15 per cent of our available water power has been developed, and that the total undeveloped water power of this country reaches the sum of thirty-five million horse-power. The development of this work, while it calls for the services of the civil engineer to design the dams, water-wheels and power-houses, requires the electrical engineer to design the generators, transformers, transmission lines and the regulating and measuring equipment. Other fields of application demanding no mean share of high grade engineering ability are the telephone and telegraph facilities of the country. The main trend in these fields is toward the simplification of the apparatus. The subject of engineering specifications, the relations of the consulting engineer and the contractor, and engineering ethics, were briefly touched upon.

San Francisco

The November meeting of the San Francisco Section was held on December 1, 1911. A paper on "The Reconstruction of a 20,000 H.P. Hydroelectric Power Plant" was presented by Messrs. J. G. Henry, Jr., and J. H. Hanson.

The regular December meeting was postponed on account of the holidays.

Toledo

The Toledo Section held its regular monthly meeting on January 5, at the Toledo Commerce Club. Mr. Tyler Green, city electrician, presented a paper on "The Relation of the Electric Signal Systems to the Fire and Police Departments as Operated in Toledo." The paper dealt with the early history of electric signal systems, and gave a detailed description of the alarm boxes used in Toledo and the system of operation by 760 cells of storage battery. At the close of the discussion the members made a trip to fire and police headquarters, where the apparatus in use was shown and explained.

Toronto

The Toronto Section held its regular monthly meeting on Friday evening, December 15, 1911, in the Engineering Building of the University of Toronto. There was a total attendance of about 55 members. Mr. H. W. Price, of the electrical engineering department of the University of Toronto, gave an interesting lecture on "The Oscillograph," which was illustrated by an oscillograph in the lecture hall, also by lantern slides showing the different parts so that the instrument might be more easily understood by those present. At the conclusion of the lecture Mr. Price gave a demonstration of the instrument.

At the next regular meeting of the Toronto Section, held on January 5, 1912, at the Engineers' Club, Mr. G. M. Gest, of New York, presented a paper on "Conduit Construction for Electrical Purposes." Mr. Gest reviewed the history of the use of conduits for telephone and electric purposes, and then gave a detailed description of modern conduit practice, which was illustrated by stereopticon views and moving pictures. Moving pictures of the conduit construction were of particular interest.

This is the first instance where moving pictures have been used in Toronto to describe engineering work. The meeting was well attended, about 100 members being present.

WASHINGTON, D. C.

The January meeting of the Washington Section was held on January 9 in the Telephone Building. A most complete description, profusely illustrated by lantern slides, of the new steam turbine generating station of the Capital Traction Company, was given by Mr. John H. Hanna, chief engineer of that company. This station, which is located upon the bank of the Potomac River in Georgetown, is arranged to receive its coal supply either by water or by rail, and is in every way typical of the best engineering practice in modern power station design. Besides the sub-station equipment located in the generating station, there are two sub-stations served with high tension current from the generating station, and since these and the generating station are all located within the Washington city limits, the 6600-volt, three-phase transmission circuits are exclusively in underground cable. Following the presentation of the paper there was a discussion which was participated in by Messrs. R. A. Carle, R. H. Dalgleigh, H. C. Eddy and others.

Past Branch Meetings

ARMOUR INSTITUTE OF TECHNOLOGY

The Armour Institute Branch held its regular meeting on December 13, 1911. Mr. P. A. Strong, class of '12, addressed the members on "The Chicago and Northwestern Railway Terminal Signal Equipment." Mr. Strong first gave an explanation of the usual operations of block signals. It was then shown how these operations were applied in the particular installation under discussion. Several diagrams were exhibited and explained, thus making clear numerous details connected with the operation of signals and switches.

UNIVERSITY OF CINCINNATI

The University of Cincinnati Branch, which has been inactive for some time, was reorganized at a meeting held on December 14, 1911. The following officers were elected: Chairman, W. H. Jefferson; vice-chairman, Max Zange; secretary, Oscar Plueddemann; executive committee, W. H. Jefferson, Max Zange, H. B. Cook, R. J. Paulsen, A. M. Wilson.

UNIVERSITY OF COLORADO

A meeting of this Branch was held on December 6. The members were addressed by Professor H. T. Plumb, on "Theory and Practice of Car Braking."

LEHIGH UNIVERSITY, SOUTH BETHLEHEM, PA.

The regular monthly meeting of this Branch was held in the physics laboratory on Thursday evening, December 14, 1911.

The first speaker was Mr. C. D. Kester, '12, who gave a talk on "Electric Versus Steam Locomotives." The talk embodied a complete comparison of the two types of locomotive with regard to fuel cost, attendants, cost of power-houses, sub-stations, also a comparison of the different speeds and tractive efforts obtainable.

Mr. E. H. Austin, '12, was the next speaker, and gave a talk on "Costs of Industrial Power," in which he discussed the various power systems, their relative costs, and the economic side of the question.

The chief speaker of the evening was Professor Charles F. Scott, head of the electrical engineering department at Yale University. Professor Scott spoke on the subject, "A Typical Central Station." As an example of the typical central station, the one at Hartford, Conn., was chosen, and the speaker traced the advance of this station from its earliest methods to the present practice.

LEWIS INSTITUTE OF TECHNOLOGY

The Lewis Institute Branch held its first meeting for the school year of 1911-1912 on November 24, 1911. Three hundred and forty-five members and visitors were present. The meeting was addressed by Professor Robert Andrews Milliken, of the University of Chicago, on the subject "Atomic Electricity." The talk dealt with Professor Milliken's researches in electricity at the university, and lantern slides added greatly to its interest. The development of the present theories of the nature of matter and electricity formed an important part of the talk, but the most interesting part was that in which Professor Milliken described his apparatus and the experiments which he performed.

At the close of the lecture, Mr. Ralph W. Pope, Honorary Secretary of the American Institute of Electrical Engineers, made a few brief remarks on the importance of the work of Professor Milliken, and congratulating the Branch on having such an eminent scientist address them.

UNIVERSITY OF MAINE

The University of Maine Branch held its regular meeting on December, 20. Professor Ganong, of the electrical engineering department, gave a talk on "European Transportation."

UNIVERSITY OF MICHIGAN

The regular meeting of this Branch was held on December 12, with a total attendance of 46 members. Mr. A. R. Fishback, district manager of the Electric Controller and Manufacturing Company, gave a lecture on "The Application of Electricity to the Manufacture of Steel."

UNIVERSITY OF MISSOURI

This Branch held a meeting on December 11. A paper on "Oil Circuit Breakers" was read by Mr. R. Kennard. Mr. Kennard discussed the history of circuit breakers and the development of the oil break. He spoke of the factors which determine the design, and followed with a description of the designs adopted by several manufacturers.

A paper on "Power Limiting Reactances" was then presented by Mr. G. B. Randall. Mr. Randall discussed the development of the modern central station and the large amount of short circuit energy resulting from the present concentration of power into huge stations. This led to the introduction of reactances in the machine leads and feeders. Mr. Randall gave the theory of the action of these reactances and showed their value.

OHIO STATE UNIVERSITY

The Ohio State University Branch held its first meeting for the school year of 1911-1912 on October 19, 1911. Mr. Mercer gave an address on "Wireless Telegraph Apparatus."

The Branch gave a banquet at Ohio Union on November 2, which was attended by 60 members and guests. Speeches were made by Dean Orton of the Engineering College, and Professors Caldwell and Hunt.

At the next meeting, held on November 16, plans were discussed looking towards the formation of a general engineering club. Mr. W. H. Abbott reported that steps were being taken towards having an engineers' rally in the near future. The address of the evening was given by Mr. E. C. Raney, on the subject, "Steam and Electrical Hoisting Apparatus."

Another meeting was held on December 7. Mr. Manly, of the Columbus Bell Telephone Company, addressed the members on the subject, "Telephone Circuits and a Description of the New York to Denver Circuit."

OKLAHOMA AGRICULTURAL AND MECHANICAL COLLEGE

The first meeting of this Branch since its authorization by the Institute Board of Directors last fall was held on January 13. Thirteen members were present, and the following papers were read: "Transmission Line of Great Falls Power Company," by M. Hibgen; "Comments on Fixed Costs in Industrial Powe- Plants," by J. C. Parker, read by Mr. F. Comstock; "Electric Power in the Construction of the Los Angeles Aqueduct," by E. F. Scattergood, read by Mr. H. Lynch; "Transmission Line Crossings," by A. H. Babcock, read by Mr. C. Coburn.

UNIVERSITY OF OREGON

At the December meeting of the University of Oregon Branch, held on December 12, 1911, Mr. C. R. Reid abstracted the paper by W. L. R. Emmet, on "Electric Ship Propulsion," presented at the Schenectady-Pittsfield Convention, and appearing in the February 1911 PROCEEDINGS.

RENSSELAER POLYTECHNIC INSTITUTE, TROY, N. Y.

The eighth meeting of the Rensselaer Polytechnic Institute Branch was held in the Russell Sage Laboratory, Troy, N.Y., on December 5, 1911. A paper on "The Electrical Properties of Alloys" was read by Dr. M. A. Hunter. Dr. Hunter described various types of alloys and showed the effect of each type on electrical conductivity and the temperature coefficient of electrical resistance.

ROSE POLYTECHNIC INSTITUTE, TERRE HAUTE, IND.

The second meeting of the Rose Polytechnic Institute Branch was held in the physics room of the Institute on Friday evening, January 5. The subject of the meeting was "Arc Lighting," and the article written by Dr. C. P. Steinmetz, appearing in the *General Electric Review* for December 1911, was read. Mr. M. J. Musser, engineer of the Terre Haute, Indianapolis and Eastern Traction Company, was present at the meeting, and had arranged to have a number of arc lamps on hand to illustrate the different methods of lighting referred to by Dr. Steinmetz in his paper. Mr. Musser described the various types of lamps and answered many questions regarding their operation.

The program concluded with a discussion of the terms "luminescence" and "incandescence" by Dr. C. L. Mees and Dr. E. S. Johonnott.

UNIVERSITY OF TEXAS

The University of Texas Branch held a meeting on November 20, at which officers for the year were elected as follows: Chairman, J. A. Correll; secretary, N. H. Brown; executive committee, J. H. Moseley, K. S. Deichman, and S. W. Aldridge.

UNIVERSITY OF VERMONT

Mr. Fred B. Wright, of the Western Union Telegraph Company, New York, addressed the members of the University of Vermont Branch at a meeting held in Williams Science Hall on December 19, 1911. Mr. Wright, since his graduation from the university in 1905, has been connected with the General Electric Company, the faculty of the University of Vermont, and the Western Electric and Western Union companies. From this experience with these corporations he gave his observation on what the business world requires of the college man. Mr. Wright mentioned as three important essentials of the college man, the ability to do work thoroughly and well, good judgment, and self-confidence. The speaker distinguished between self-confidence and conceit, and stated that the college man should not think that he knows more than the man at his elbow who is without college training. Mr. Wright concluded his talk with a few remarks about the organization of the American Telephone and Telegraph Company.

WASHINGTON UNIVERSITY,
ST. LOUIS, MO.

The second regular meeting of the Washington University Branch was held on Tuesday, December 19, 1911. Owing to the failure of the speaker scheduled for the evening to attend the meeting, Professor George W. Lamke gave a talk on "Incandescent Lamps." Brief talks were also given by Mr. A. W. Lambert, on "The Interborough Subway," and "The Interborough Power House," by Chairman Cheney. The meeting was held jointly with the Washington University Branch of the American Society of Mechanical Engineers.

Cornell Alumni Reunions

The Cornell Alumni in attendance at the monthly meetings of the American Institute of Electrical Engineers in New York are forming the habit of getting together for dinner at the Cornell University Club, 65 Park Avenue. A large and representative attendance has already been built up and all are enthusiastic as to the possibilities of the plan in promoting interest in the Institute, and in forming and renewing college ties. Cornellians who expect to attend the reunions should notify the steward of the club a few days in advance, and for the purpose of these reunions the club has extended its privileges to non-member Cornellians.

United States Army and Navy Officers at Massachusetts Institute of Technology

Following the custom of recent years, the United States Government has sent officers of the army and navy to the Institute to receive instruction in electrical engineering. These are in addition to the graduates of the Naval Academy who are sent to take a course in naval architecture. This year the Naval Academy is represented by Ensign G. K. Calhoun who was graduated from Annapolis in 1908. He has recently been stationed at the United States Naval Observatory at Washington where he has done considerable original work in wireless telegraphy, ship propulsion, gyroscopic compasses and chronometers.

The army is represented by Captain Edward Canfield, West Point, 1901, and First Lieutenant F. Q. C. Gardner, West Point, 1904. Both officers have been connected with the Coast Artillery Corps, Captain Canfield being stationed at Puget Sound and Lieutenant Gardner at Fortress Monroe. Both men will pursue a special course in electrical engineering.

Personal

MR. ROBERT F. TRENNERT has resigned as electrician with the Great Western Power Company, San Francisco, to accept his old position as electrician on the Los Angeles Aqueduct.

MESSRS. DWIGHT P. ROBINSON and JOHN W. HALLOWELL were admitted into partnership, on December 30, 1911, in the firm of Stone and Webster, of Boston, Mass.

MR. CALVERT TOWNLEY, of the New York office of the Westinghouse Electric and Manufacturing Company, was married on December 30, 1911, to Mrs. Mabel McCormick Steele, of Memphis, Tenn.

MR. F. C. GREEN, formerly with the Oregon Electric Railway Company, has entered the electrical contracting business with the firm of E. L. Knight and Company, 291 East Morrison St., Portland, Oregon.

MR. E. J. YOUNG, electrical engineer of the Temiskaming and Northern Ontario Railway, has resigned his position in order to become chief electrical engineer of the National Transcontinental Railway, with headquarters at Ottawa, Ontario.

MR. RAY FLAGG has left the Wagner Electric Manufacturing Company, after being in the employ of that company for six and a half years, to become electrical engineer with the Hisey-Wolf Machine Company, of Cincinnati, Ohio.

Mr. C. V. Turner has resigned as electrical engineer with the Pierce Phosphate Company to accept the position of electrical and mechanical engineer and assistant superintendent of the Amalgamated Phosphate Company, Chicora, Polk County, Florida.

Mr. W. E. Hawley, for the last four years with the Post-Glover Electric Company of Cincinnati, and formerly with the Crouse-Hinds Company, of Syracuse, has accepted the position of sales engineer with the J. Lang Electric Company, of Chicago.

Mr. A. K. Selden, Jr., who for some years has been in charge of the design of interpole adjustable speed motors manufactured by the Electro Dynamic Company, has joined the engineering department of the Crocker-Wheeler Company, Ampere, N. J.

Mr. J. H. Siegfried has resigned as superintendent of the light and power department of the City of Winnipeg, Manitoba, to accept the position of superintendent of power with the Pacific Power and Light Company, recently made vacant by the death of Mr. L. N. Young.

Mr. J. W. McCrosky, general foreign representative of J. G. White and Company, Ltd., of London, sailed from Southampton on January 6th for the Amazon Valley in connection with important business interests and negotiations which his company has in hand in Brazil.

Mr. W. J. Warder, Jr., formerly chief engineer and superintendent of Roth Brothers, Chicago, and who was later connected with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, has joined the sales department of the Crocker-Wheeler Company, Ampere, N. J.

Mr. Walter J. Jones, consulting engineer, 30 Church Street, New York City, has been appointed engineer to the Electrical Commission of the City of Montreal, P. Q. He will have immediate supervision over the work of gathering data and laying out a municipal underground conduit system for that city.

Mr. Henry Floy, consulting engineer, of New York City, has been engaged by J. B. Mayer, receiver of the Twenty-eighth and Twenty-ninth Sts. Crosstown Railroad, New York City, to appraise the property of that company for use in connection with the reorganization of the company and at the hearings before the Public Service Commission, First District.

Mr. Arthur C. Morse has been appointed sales engineer in the New York office of Crocker-Wheeler Company. Mr. Morse has had ten years' experience in the sales department of the Western Electric Company, and for the past three years has been the New York district sales manager of the electrical department of the Taunton New Bedford Copper Company, manufacturers of switchboards, panelboards, switches, etc.

Mr. W. J. Miskella, for several years in the engineering departments of the Western Electric Company, has resigned, and is now sales engineer of the Duplicator Manufacturing Company, 970 Old Colony Building, Chicago, Ill. Mr. Miskella will devote his time to the application, in the engineering departments and general office work, of the commercial duplicator, a labor saving machine which eliminates the use of carbon and hand processes of duplicating.

Obituary

Mr. Charles Coit Cokefair, president and general manager of the Great Northern Development Company and subsidiary corporations, died at his home, 2302 East Fifth Street, Duluth, Minn., on Wednesday morning, December 13, 1911. Death was due to pneumonia, which had confined him to his home for two weeks.

Mr. Cokefair was born at Bloomfield, N. J., on April 3, 1848. He received his early education in the public schools and at the Pennington Seminary, Pennington, N. J. For the last thirty-five years he has been engaged in the organization and management of mining, power and other industrial concerns. He organized the Great Northern Development Company of Duluth, and as president and general manager of that company acquired the necessary lands, riparian rights, and permits from Congress. He was an acknowledged expert in the development of water power propositions, and his great success was due to his enthusiasm in his work and confidence in his ability to carry his undertakings to a successful termination. Besides his connection with the Great Northern Development Company, Mr. Cokefair was president of the Interurban Power Company of Minneapolis, director in the Great Northern Power Company of Duluth, and director in the Mississippi River Power Company of Minneapolis, and of the Upper Mississippi River Improvement Association. He was a member of the Kitchi Gammi Club, the Country Club and Commercial Club, the Duluth Boat and Yacht Club of Duluth, and an Associate of the American Institute of Electrical Engineers. He became an Associate of the Institute on October 26, 1906.

Mr Cokefair was married on September 30, 1868, to Miss Elsie J. Albertson, of Warren County, N. J., who, with their son, Francis A. Cokefair, a civil and hydraulic engineer, survives him.

Mr. Charles I. Young, of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and formerly chairman of the Philadelphia Section of the American Institute of Electrical Engineers, died on Saturday morning, January 6th. Mr. Young had been failing in health for the last year, and in November he sought to improve his condition by going to a sanitarium for treatment. As the result of an electric shock of 2,500 volts received in 1888, he was incapacitated for work for three years following the accident. He suffered also from malarial fever during the same period. In 1891 he returned to Pittsburgh to resume work with the Westinghouse Company, and although physically he was weak and partially dependent upon the help of another, his electrical knowledge fitted him admirably for work in the sales department as an advisory engineer. Subsequently he was transferred to the export department in New York, and later to the Philadelphia office. He took an active interest in the affairs of the Philadelphia Section of the American Institute of Electrical Engineers, and on June 13, 1910, he was elected chairman of that Section. The following memorial was adopted by the Philadelphia Section at its meeting held on January 17, 1912:

> The Officers and Members of the Philadelphia Section of the American Institute of Electrical Engineers hereby wish to express to the relatives of Charles I. Young their sense of personal loss at his untimely death.
>
> As a member and recent Chairman of the Section, we have been associated with him in relations that have been professional, social and individual and in all these relations he has ever shown a sterling honesty and uprightness of character that have proved him to be a gentleman of the highest type, a man of unquestioned integrity.
>
> By the kindliness of his greeting and by the nobility of his life, he has won from us an affectionate regard that makes the remembrance of his friendship a real and lasting treasure.
>
> January 17, 1912.

In October, 1910, Mr. Young was transferred to the commercial training department in the sales organization of the Westinghouse Company, as instructor. Classes are formed from time to time from the district offices of the Company and brought to headquarters to be made acquainted with the latest development of the apparatus and with the methods of selling. In this latter work Mr. Young realized to the fullest extent his ambition to serve best the interests to which he had been attached for so long. His pleasing personality and knowledge of human nature made him a force among men. Mr. Young was graduated from Princeton in 1883, following which he was employed by the Edison Machine Works at New York testing generators during 1884 and 1885. Later he became superintendent of the Edison Illuminating Company. He became attached to the Westinghouse interests in 1886. He was elected an Associate of the Institue on June 27, 1895. Mr. Young is survived by his brother, Captain F. A. Young, an attache of the United States Weather Bureau at Washington.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Allgemeine Elektrotechnik. By E. Kittler. (III Band. Wechselstrommaschinen—Petersen). Stuttgart, 1910. (Purchase.)

American Mining Congress. Report of Proceedings 14th Annual Session, 1911. Denver, 1911. (Gift of American Mining Congress.)

American Railway Association. Proceedings. Nov. 15, 1911. New York, 1911. (Gift of American Railway Association.)

American Society of Agricultural Engineers. Transactions Vol. III, IV, 1909–10. n.p.n.d. (Gift of Society.)

Applied Electrochemistry. By M. deKay Thompson. New York, 1911. (Purchase.)

Die Autogene Schweiss und Schneidetechnik. By August Horn. Halle a. S. 1911. (Purchase.)

Caoutchouc et Gutta-Percha. By E. Tassilly. Paris, 1911. (Purchase.)

Code of Ordinances of the City of New York, as approved Nov. 8, 1906. Compiled by A. F. Cosby, New York, 1911. (Purchase.)

Direct Current Machine Design. By F. B. Crocker. New York, 1908. (Purchase.)

Electrical Distributing Networks and Transmission Lines. By Alfred Hay. London-New York, Cassell & Co., 1910. (Purchase.)

Elementary Lectures on Electric Discharge, Waves and Impulses, and other Transients. By C. P. Steinmetz. New York, 1911. (Purchase.)

Die Entwicklung der Wechselstrombahnen. By Eugen Eichel. (Sonderabdruck Vereins Deutscher Strassenbahn und Kleinbahn Verwaltungen, Sept. 22, 1911). N.p. n.d. (Gift of author.)

Experimental Electrical Engineering and Manual for Electrical Testing. Vols 1-2, Ed. 2. By V. Karapetoff. New York, 1911. (Purchase.)

Hochspannungs-technik. By W. Petersen. Stuttgart, 1911. (Purchase.)

Institution of Engineers & Shipbuilders in Scotland. Transactions. Vol. LIV. Glasgow, 1911. (Gift of Institution of Engineers & Shipbuilders in Scotland.)

Lexikon der Gesamten Technik und ihrer hilfswissenschaften. Ed. 2, Vols. 1-8. By Otto Lueger. Stuttgart, 1904. (Purchase.)

List of Electrical Fittings, October, 1911. Published by the National Board of Fire Underwriters at the recommendation of Underwriters Laboratories, Inc., N.p. 1911. (Gift of Underwriters Laboratories, Inc.)

McGraw Electrical Directory—Electric Railway Edition, August, 1911. New York, 1911. (Purchase.)

——Lighting and Power Edition. October, 1911. New York, 1911. (Purchase.)

Modern American Telephony in all its Branches. By A. B. Smith. Chicago, 1911. (Purchase.)

New York Society of Architects. Official Year Book, 1911. New York, 1911. (Gift of New York Society of Architects.)

New York State-Public Service Commission, First District Proceedings. Vol. 5, 1910. New York, 1910. (Exchange).

Observation with the Dipping Needle at Boston in 1722. By H. E. Ware. Cambridge, 1911. (Gift of Author.)

Ohio State University. Alumni Register, 1878-1909. Columbus, 1909. (Gift of Ohio State University.)

Oklahoma Geological Survey. Preliminary Report on the Road Materials and Road Conditions of Oklahoma. (Bulletin No. 8.) Norman, 1911. (Gift of Oklahoma Geological Survey.)

Plumbing and House Drain Inspection. (Milwaukee Bureau of Economy and Efficiency. Bulletin No. 10.) By F. H. Elwell. Milwaukee, 1911. (Gift.)

Principles of Direct Current Electrical Engineering. By J. R. Barr. London, N. Y., 1908. (Purchase.)

Proper Distribution of Expense Burden. By A. H. Church, New York, 1908. (Purchase.)

Railroad Gazette. Vols. 6, 18–29, 31–34. New York, 1874, 1886–1902. (Gift of C. O. Mailloux.)

Die Regelung der Kraftmaschinen. Ed. 2. By Max Tolle. Berlin, 1909. (Purchase.)

Regelung, Umsteureung und Sicherung der Dampfturbinen für ortsdeste Betriebe, Land und Wasserfahrzeuge. By W. Gentsch. Hannover, 1908. (Purchase.)

Rubber. By Philip Schidrowitz. London, 1911. (Purchase.)

Starkstromtechnik Taschenbuch fur Elektrotechniker. By E. v. Rziha and J. Seidener. Berlin, 1909. (Purchase.)

Steam Turbines with an Appendix on Gas Turbines and the Future of Heat Engines. Ed. 2. By A. Stodola and L. C. Loewenstein. New York, 1906. (Purchase.)

Uber die Stromabnahme mit Besonderer Berücksichtigung Hoher Geschwindigkeiten. By J. E. Noeggerath Munchen, 1911. (Gift of author.)

Telegraphen und Fernsprechkabelanlagen. By C. Stille Braunschweig, 1911. (Purchase.)

Toute la Chimie Minerale par l'Electricité. Ed. 2. By Jules Séverin. Paris, 1910. (Purchase.)

U. S. Library of Congress. Report of Librarian, 1911. Washington, 1911. (Gift of Library of Congress.)

University of Missouri. Directory of the Alumni, April, 1911. N.p. 1911. (Gift of University of Missouri.)

Wasserkraftmaschinen. Ed. 2. By L. Quantz. Berlin, 1911. (Purchase.)

Die Wasserturbinen ihre Berechnung und Konstruktion. By R. Thomann. Stuttgart, 1908. (Purchase.)

Zeitschrift des Osterreichischen Ingenieur und Architekten Verein. 1861, 1877, 1881–82, 1884, 1886–1888, 1890–1891, 1893–1897, 1901. Wien, 1861, 1877, 1881–2, 1884, 1886–88, 1890–91, 1893–97, 1901. (Gift of C. O. Mailloux.)

TRADE CATALOGUES

Allegemeine Elektricitäts Gesellschaft. Berlin. Turbo-boiler feed pumps. 16 pp.

H. B. Camp Co., New York. Vitrified salt glazed conduits for electrical subways. 42 pp.

General Electric Co., Schenectady, N. Y. Bull No. 4892—Battery truck crane. 9 pp

——Bull. No. 4895—Electric fans. 39 pp.

——Bull. No. 4897—G. E. Edison Mazda lamps for standard train lighting service. 10 pp.

——Bull. No. 4899—Expulsion fuses and fuse holders. 18 pp.

Bull. No. 4902—D. C. switchboards, 125–250 volts, 3-wire. 14 pp.

——Bull. No. 4908—The lighting of hotels, cafes, and clubs. 40 pp.

——Bull. No. 4912—G. E. ozonators; ozone and ventilation. 14 pp.

Otto Bennert & Co., München. Electric regulation of temperatures and pressures. 14 pp.

——Description of the Rennert temperature regulator. 18 pp.

——Ten pamphlets, illustrating various regulators and showing their application. 40 pp.

Wagner Electric Mfg. Co., St. Louis, Mo. Bull No. 97—Single-phase converter and five photographs of the same. 6 pp.

UNITED ENGINEERING SOCIETY

Autobiography of John Fritz. New York, 1912. (Gift of John Fritz.)

American Vanadium Co. Pittsburgh, Pa. 9 Photographs of vanadium steel machine parts. 9 pp.

H. Channon Co., Chicago. Ill. Machinery and general supplies for railroads, manufacturing and power-plants. 952 pp.

Du Pont de Nemours Powder Co., Wilmington, Del. Use of explosives on the farm. 118 pp.

——Dynamiting boulders and stumps. 28 pp.

——Tree planting with Du Pont dynamite. 24 pp.

Fay & Egan Co., Cincinnati, O. Woodworking machinery. 384 pp.

Forbes Co., Philadelphia, Pa. Water sterilization by heat. 80 pp.

Munning-Loeb Co., Matawan, N. J. Belt driven and motor driven electro-plating dynamos. 19 pp.

Tinius Olsen & Co., Philadelphia, Pa. Part A.—Catalogue of testing machinery and instruments. 66 pp.

——Part B.—Spring testing machinery. 16 pp.

——Part C—Cement testing apparatus. 19 pp.

——Part D—Fiber, paper, glue, rubber testing machinery. 12 pp.

——Part E—Wire, chain, anchor testing machinery. 20 pp.

——Part F—Oil, grease, bearing metal testing machinery. 10 pp.

——Part G—Transverse testing machinery. 8 pp.

——Part H—Special testing machinery. 24 pp.

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL.

DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER.	(Term expires July 31, 1912.)	SECRETARY.
GEORGE A. HAMILTON.		F. L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN WILLIAM LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH W. POPE,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

STANDING COMMITTEES.

Revised to February 1, 1912.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
F. L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York.
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
JOHN PRICE JACKSON, State College, Pa.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, Brooklyn.
PERCY HOLBROOK THOMAS, New York.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE.

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

STANDARDS COMMITTEE.

ARTHUR E. KENNELLY, Chairman,
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Secretary,
Harvard University, Cambridge, Mass.
FREDERICK BEDELL, Ithaca, N. Y.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Perth Amboy, N. J.
BENJAMIN G. LAMME, Pittsburgh, Pa.
WILBUR L. MERRILL, Schenectady, N. Y.
HAROLD PENDER, Boston, Mass.
WILLIAM H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburgh, Pa.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
J. FRANKLIN STEVENS, Philadelphia, Pa.

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
CLIFTON V. EDWARDS, New York.
FRED S. HUNTING, Fort Wayne, Ind.
ADDAMS S. McALLISTER, New York.

SPECIAL COMMITTEES.

Revised to February 1, 1912.

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman,
165 Broadway, New York.
EDWIN BRITTON KATTE, Vice-Chairman,
New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

JOHN PRICE JACKSON, Chairman,
State College, Pa.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman,
General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, Brooklyn, N. Y.
PERCY HOLBROOK THOMAS, New York.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman,
120 W. Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman,
Allis-Chalmers Co., Milwaukee, Wis.
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York.
BARTON ROY SHOVER, Youngstown, Ohio
ROBERT BELDEN TREAT, Ampere, N. J.
R TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE.

BANCROFT GHERARDI, Chairman,
15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York.

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman,
360 Pearl Street, Brooklyn, N. Y.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
CLYDE D. GRAY, New York.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa.

SPECIAL COMMITTEES.—Continued.

Revised to February 1, 1912.

PUBLIC POLICY COMMITTEE.

JOHN J. CARTY, Chairman,
15 Dey St., New York.
HAROLD W. BUCK, New York.
JOHN H. FINNEY, Washington, D. C.
PAUL N. NUNN, Provo, Utah.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

ADDITIONAL GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman,
2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.

MEMBERSHIP COMMITTEE.

CHARLES E. SCRIBNER, Chairman,
463 West Street, New York.
S. B. CHARTERS, San Francisco, Cal.
HENRY FLOY, New York.
GEORGE W. LAMKE, St. Louis, Mo.
A. A. MILLER, Seattle, Wash.
N. J. NEALL, Boston, Mass.
K. C. RANDALL, Pittsburgh, Pa.
DAVID B. RUSHMORE, Schenectady, N. Y.
A. M. SCHOEN, Atlanta, Ga.
H. CLYDE SNOOK, Philadelphia, Pa.
H. B. STABLER, Baltimore, Md.
J. G. WRAY, Chicago, Ill.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman,
52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

CODE OF ETHICS COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J.

ELECTROPHYSICS COMMITTEE.

EDWARD B. ROSA, Chairman,
Bureau of Standards, Washington, D. C.
EDWARD P. HYDE, Cleveland, O.
MALCOLM MACLAREN, Princeton, N. J.
EDWARD L. NICHOLS, Ithaca, N. Y.
HAROLD PENDER, Boston, Mass.
MICHAEL I. PUPIN, New York.
HARRIS J. RYAN, Stanford University, Cal.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
JOHN B. WHITEHEAD, Baltimore, Md.
FRANK A. WOLFF, Washington, D. C.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman,
29 West 39th St., New York
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

INDEXING TRANSACTIONS COMMITTEE.

GEORGE IRVING RHODES, Chairman,
600 West 59th Street, New York.
MORTON GITHENS LLOYD, Chicago, Ill.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President.
90 West St., New York.
ARTHUR E. KENNELLY, Secretary,
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Cambridge, Mass.
LOUIS BELL, Boston, Mass.
JOHN J. CARTY, New York.
GANO DUNN (ex-officio), New York.
CARL HERING, Philadelphia, Pa.
JOHN W. HOWELL, Newark, N. J.
JOHN W. LIEB, Jr., New York.
RALPH D. MERSHON, New York.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
SAMUEL W. STRATTON, Washington, D. C

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.

FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.
W. D. WEAVER, New York.

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP PRICE BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913.

COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y.

Term expires July 31, 1912.

WILLIAM S. BARSTOW, New York.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.

LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, Brooklyn, N. Y.

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.

GANO DUNN, President, New York.
F. L. HUTCHINSON, Secretary.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

Revised to February 1, 1912.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

LOUIS A. FERGUSON, Chicago, Ill.
LEWIS BUCKLEY STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.
GANO DUNN, New York.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

CALVERT TOWNLEY, New York.
HENRY G. STOTT, New York.
GANO DUNN, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, New Haven, Conn.
SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.
ELIHU THOMSON, Swampscott, Mass.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

EDWARD B. ROSA, Washington, D. C.
JOHN B. WHITEHEAD, Baltimore, Md

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

JOHN J. CARTY, New York.
CALVERT TOWNLEY, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE, G. P. O., Perth, Australia.
HORACE FIELD PARSHALL, Salisbury House, London Wall, E. C., London.
L.A. HERDT, McGill University, Montreal, Que.
WILLIAM G. T. GOODMAN, Adelaide, South Australia.
ROBERT JULIAN SCOTT, Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

LIST OF SECTIONS.

Revised to February 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Atlanta............Jan. 19, '04	A. M. Schoen.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore..........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	William L. Hooper.	G. A. Rodenbaeck, 84 State St., Boston, Mass.
Chicago..................1893	J. G. Wray.	
Cleveland.........Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne........Aug. 14, '08	E. A. Wagner.	A. B. Morrison, 817 Nelson Street, Ft. Wayne, Ind.
Indianapolis-Lafayette.Jan. 12, '12		
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	O. H. Ensign.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal
Madison..........Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Lynn............ Aug 22, '11	E. E. Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass.
Mexico.. ....Dec. 13, '07	W. H. Fiske.	H. S. Foley, Apartado 124 Bis., Mexico, D. F.
Milwaukee........Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	Chas. L. Pillsbury.	Leo H. Cooper, 805 Metropolitan Life Bldg., Minneapolis, Minn.
Philadelphia.......Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg..........Oct. 13, '02	K. C. Randall.	E. L. Farrar, G. E. Co., Oliver Bldg., Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass
Portland, Ore......May 18, '09	F. D. Weber.	H. R. Wakeman, 604 Electric Building. Portland, Ore.
San Francisco.....Dec. 23, '04	S. B. Charters.	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo
Toledo...........June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto...........Sept. 30, '03	A. L. Mudge.	Valentine Boyd, 212 King St., West, Toronto, Ont.
Urbana...........Nov. 25, '02	E. H. Waldo.	F. G. Willson, University of Illinois, Urbana, Ill.
Vancouver........Aug. 22, '11	F. D. Nims.	E. M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D. C..Apr. 9, '03	Earl Wheeler.	H. C. Eddy, Interstate Commerce Commission, Washington, D. C.

Total, 28

LIST OF BRANCHES.

Revised to February 1, 1912.

Name and when Organized	Chairman	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	C. E. Greene	M. L. Johnson, College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. H[illegible], University of Arkansas, Fayetteville, Ark
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
Case School, Cleveland Jan. 8, '09	S. G. Boyd	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio
Cincinnati, Univ. of..Apr. 10, '08	W. H. Jefferson.	Oscar Paul Hen[illegible], University of Cincinnati, Cincinnati, O
Colorado State Agricultural College.......Feb. 11, '10	D. E. Byerley.	A. A. Catlin, 626 So. Meldrum St., Fort Collins, Colo.
Colorado, Univ. of..Dec. 16, '04	L. R. Leonard.	W. C. DuVall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	L. J. Kieser.	A. H. Ford, University of Iowa, Iowa City, Ia
Kansas State Agr. Col. Jan. 10, '08	B. F. Hillebrandt	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. H[illegible]s, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of................Oct. 14, '10	W. H. Jaegle.	J. H. Gaser, 341 Harrison Ave., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa
Lewis Institute......Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	Benjamin Haskell	John E. Ash, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, Ann Arbor, Mich
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	J. Glen Luther	J. A. Thaler, Montana State College, Bozeman, Mont
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N. C. C. A. and M. A., West Raleigh, N. C
Ohio State Univ......Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio
Oklahoma Agricultural and Mech. Coll....Oct. 13, '11	W. E. Dolde.	
Oregon State Agr. Col.Mar. 24, '08	H. Belknap	W. R. Varner, Oregon St. Agric. College, Corvallis, Ore
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa
Purdue Univ.........Jan. 26, '03	C. F. Harding	A. L. Topping, Purdue University, Lafayette, Ind
Rensselaer Polytechnic Institute...........Nov. 12, '09	E. D. N. Schulte	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Rose Polytechnic Inst Nov. 10, '11	Jerry H. Service, Jr.	David W. Jones, 911 North 8th Street, Terre Haute, Ind.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.......Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y
Texas, Univ. of.......Feb. 14, '08	J. A. Correll	N. H. Brown, University of Texas, Austin, Tex.
Throop Polytechnic Inst...............Oct. 14, '10	Frank C. Miller.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	O. Krupp, 65 North Bend St., Burlington, Vt.
Wash., State Coll. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Irwin L. Cheney.	P. S. Stevens, Washington University, St. Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles P. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.
Yale University......Oct. 13, '11	B. C. Beck.	J. H. Shallenberger, 166 Vanderbilt-Scientific, New Haven, Conn.

Total, 39.

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

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THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Next Regular Meeting of the A.I.E.E., New York, March 8, 1912

The two hundred and sixty-ninth meeting of the A.I.E.E. will be held in the Auditorium of the Engineers Building, 33 West 39th Street, New York, on Friday, March 8, 1912, at 8:15 p.m. Two papers will be presented at this meeting, under the auspices of the High Tension Transmission Committee, as follows:

"Characteristics of Protective Relays," by Mr. E. M. Hewlett.

"Some Problems of High-Voltage Transmissions," by Dr. C. P. Steinmetz.

Both of these papers are published elsewhere in this issue of the PROCEEDINGS.

The meeting will be called to order promptly, and will be adjourned at 10:00 o'clock, after which the usual smoker will be held in the Institute offices on the 10th floor. Light refreshments will be served.

Institute Meeting in New York, April 5, 1912

The two hundred and seventieth meeting will be held in New York on April 5, 1912, under the auspices of the Railway Committee. There will be an evening session only, beginning at 8:15 p.m., instead of both afternoon and evening sessions as announced in the February issue of the PROCEEDINGS. Mr. Samuel Insull will present a paper on "The Relation of Central Station Generation to Railway Electrification."

Meeting at Pittsburgh, April 25-27, 1912

Arrangements for the Pittsburgh meeting of the Institute, April 25–27, 1912, are well under way and the Industrial Power Committee has prepared an interesting program of papers several of which are completed and in course of publication. The papers on hand are as follows:

"The Electric Control of a Large Mine Hoist," by H. W. Cheney.

"The Use of Alternating Current in Unloading Coal," by W. N. Ryerson and J. B. Crane.

"Self-Starting Synchronous Motors," by C. J. Fechheimer.

"Electrification of a Reversing Mill at the Algoma Steel Mill," by Bradley T. McCormick.

The first two papers mentioned above are published elsewhere in this issue of the PROCEEDINGS, and the remainder of the papers for this meeting, as well as the complete program of entertainments, place of meeting, hotel headquarters, etc., will be given in the April PROCEEDINGS.

Annual Convention, Boston, June 25-28, 1912

Preparations for the Annual Convention in Boston are progressing and it is expected that the technical program will include about twenty papers. The new Copley-Plaza Hotel, which is just approaching completion, has been selected for Convention headquarters. Further details regarding transportation, etc., will be published in succeeding issues of the PROCEEDINGS.

Meeting at Schenectady, May 17, 1912

The Schenectady meeting of the Institute which was announced to be held during the month of May has been definitely fixed by the local committee for May 17, 1912. Arrangements have been made for a number of papers, principally on railway and high-tension transmission subjects. The present plan is to hold a morning and an evening session for the presentation of papers and to devote the afternoon to the entertainment features.

Pacific Coast Meeting, Portland, Ore., April 16-20, 1912

The Pacific Coast meeting, the two hundred and seventy-first meeting of the Institute, as announced in the previous issue of the PROCEEDINGS, will be held in Portland, Ore., Tuesday to Saturday, April 16–20 inclusive, 1912.

The members of the Portland Section who have been engaged in preparing for the meeting expect several interesting papers for the technical program. Two of the papers for the Portland meeting appear in this issue of the PROCEEDINGS, "Air-gap Flux Distribution in Direct Current Machines," by Charles R. Moore, and "Operation of Two Alternating Current Stations Through Parallel Circuits, and the Distribution of Load and Wattless Currents between Them," by J. W. Welsh. A paper entitled "Irrigation in the Spokane Valley," by L. J. Corbett, will be printed in the April PROCEEDINGS, together with other papers.

In addition to the technical program, excursions will be made to many points of interest, including large hydro-electric developments, and the routes to these developments lie through a country of great scenic beauty. Entertainment will be provided for the members and for the ladies who may accompany them.

The headquarters for the Pacific Coast meeting will be in the Hotel Multnomah, a new fireproof hotel in Portland's business district, with 725 rooms and suites. The following rates have been offered by the management, on the European plan:

One person in room, without bath, $1.50 to $2.00 per day.

One person in room, with bath, $2.00 to $3.00 per day.

Two persons in room, without bath, $2.00 to $2.50 per day.

Two persons in room, with bath, $3.00 to $5.00 per day.

Application for reservations should be addressed to Mr. H. C. Bowers, manager Multnomah Hotel Company, stating the kind of room desired and the price to be paid. Mr. H. R. Wakeman, secretary of the Portland Section, 609 Electric Building, Portland, Ore., will be glad to answer any inquiries regarding the coming meeting.

Resume of Business Transacted at the Meeting of the Board of Directors of the American Institute of Electrical Engineers, February 9, 1912

The meeting was attended by the following Members of the Board: President Gano Dunn, New York; Past-President Dugald C. Jackson, Boston, Mass; Vice-Presidents D. B. Rushmore and Charles W. Stone, Schenectady, N. Y.; Managers, A. W. Berresford, Milwaukee, Wis.; William S. Murray, New Haven, Conn.; Severn D. Sprong, H. H. Barnes, Jr., and W. S. Rugg, New York; Farley Osgood, Newark, N. J.; Treasurer George A. Hamilton, and Secretary F. L. Hutchinson, New York.

Monthly bills of $8,042.35 were approved for payment.

The suggestion by the Illuminating Engineering Society of a joint meeting with the American Institute of Electrical Engineers was most cordially received, and a resolution adopted giving to the President of the Institute and the chairman of the Meetings and Papers Committee power to confer with the representatives of the Illuminating Engineering Society and to arrange for such a joint meeting on satisfactory determination of date, place and other details.

Applications for admission to the Institute were considered from 114 persons, who were, on consideration of the Board, elected Associates.

Sixty-six names were added to the list of enrolled students, which already totals about 1000, and Messrs. Albert M. Allen, Charles W. Pen Dell, Arthur L. Mudge, William C. Bauer, Walter E. Holland and Samuel Insull were transferred to the grade of Member.

The vacancies in the representation of the Institute upon the Board of Trustees of the United Engineering Society caused by the resignation of Mr. Henry G. Stott and Mr. Calvert Townley, were filled by the election of Messrs. H. H. Barnes, Jr., and Walter S. Rugg.

Petitions for the establishment of Institute branches at the University of California, the Ohio Northern University and the University of Virginia, were received, and, on recommendation of the Sections Committee, were granted.

The President appointed Mr. H. W. Flashman chairman and Mr. B. K. Boyce, Mr. Frederick Borch, Mr. Robert Morris and Mr. W. C. Yates to act as a Committee of Tellers to canvass the ballots in the coming nomination and election of officers of the Institute, as provided for in the constitution.

On the unanimous recommendation of the Committee on Code of Ethics, consisting of Professor George F. Sever, Chairman, Messrs. Harold W. Buck, Samuel Reber, Charles P. Steinmetz, Henry G. Stott and Schuyler S. Wheeler, and with the approval of the following advisory members of the committee, Messrs. William S. Barstow, Louis Bell, John J. Carty, Francis B. Crocker, Dugald C. Jackson, Arthur E. Kennelly, John W. Lieb, Jr., C. O. Mailloux, Henry H. Norris, Ralph W. Pope, Harris J. Ryan, Charles F. Scott, Samuel Sheldon, William Stanley, Elihu Thomson and William D. Weaver, a revised draft of what has heretofore been called "A Code of Ethics," but which is hereafter to be called "A Code of Principles of Professional Conduct," in order to make its title more closely agree with its subject-matter, was recommended to the Board of Directors for tentative approval.

Upon recognition by the Board that certain provisions of the code relating to the use of standards, and certain other provisions which had previously been questioned, had been eliminated, the Board passed, unanimously, a resolution expressing its tentative approval and its intention to bring the code up for final action a month hence.

The Board also authorized the committee to change its name to the "Committee on Code of Principles of Professional Conduct," and invited suggestions and criticisms from members of the Board prior to February 24.

An appropriation was voted to the Committee on Notification of Honorary Members to cover the expenses of diplomas and pins for the Honorary Members elected at the meeting of January 12.

The President of the Institution of Civil Engineers of Great Britain, in a letter to the President of the Institute, invited contributions from members of the Institute towards erecting in Westminster Abbey a memorial window to the late Lord Kelvin, and asked that a committee consisting of the President of the Institute, the Secretary and two members of the Board of Directors, be appointed to coöperate with the Institution of Civil Engineers to this end. The invitation of the Institution of Civil Engineers was most cordially received, and the President was instructed to appoint the committee requested and to coöperate in every possible way in paying respect and honor to the memory of the great British scientist, who at the time of his death was an Honorary Member of the American Institute of Electrical Engineers.

In addition to the President and Secretary, Vice-President Charles W. Stone and Manager Walter S. Rugg were appointed members of this committee.

This committee, on the suggestion of Mr. Calvin W. Rice, Secretary of the American Society of Mechanical Engineers, was authorized to confer with the corresponding committees to be appointed by the other engineering societies in America.

Members returning from the Institute Convention at Panama, through Professor George F. Sever, officially designated by the Board as the presiding officer of the convention, reported a most successful trip and recommended that the meeting be officially designated a convention in view of its great success and the numerous contacts with other societies and bodies of an international character that had taken place. This recommendation was accepted, and it was authorized to put into the permanent records of the Institute, in the TRANSACTIONS, a complete report of the activities on the trip and the courtesies and hospitalities received from officers of the United States government, the Republic of Panama and other bodies there.

A resolution from the convention recommending that at the time of the International Electrical Congress in San Francisco in 1915 a convention of the Institute be held in San Francisco, and that the eastern members proceed to this convention by means of a chartered steamer through the Panama Canal, was received by the Board and referred to the Committee on Meetings and Papers.

The particular thanks of the Board were voted to Chairman Severn D. Sprong and his committee, consisting of Messrs. A. W. Berresford, H. J. Douds, F. L. Hutchinson, P. Junkersfeld, H. A. Lardner, Walter S. Rugg, David B. Rushmore, Edward Schildhauer, A. M. Schoen, Charles E. Waddell and Alexander J. Wurts, who organized the trip and arranged for the transportation and other details, and to Professor George F. Sever, who, as official representative of the Institute, was the head of the party in Panama.

The President was authorized to call the attention of the membership to the fact that the amendments to the constitution providing for a new grade of membership had been fully published in the February PROCEEDINGS with comments and explanations. He also recommended that the columns of the PROCEEDINGS be opened to letters and discussions from members on subjects of Institute interest, so that the monthly publication might be a forum where any member of the Institute could get publicity for views and issues that were of interest to the Institute generally. The Board welcomed this suggestion and passed a resolution recognizing the propriety of permitting, to a limited extent and under the supervision of the Editing Committee, the use of the columns of Section I of the PROCEEDINGS by members of the Institute for the expression of their views upon topics of current Institute interest.

The University of Pittsburgh invited the appointment of a representative to be present at the celebration of its 125th anniversary on February 27-29, for which honor Mr. Paul M. Lincoln was selected.

The report of the Special Conference Committee on General Engineering Congress at San Francisco, 1915, of which Mr. H. A. Lardner is chairman and Messrs. S. J. Lisberger and George R. Murphy are members, was read in full to the Board, and the memorial adopted by the recent conference of the National Engineering Societies at San Francisco was presented.

The President was given power to act upon this memorial in regard to its relation to the Committee on Organization of the International Electrical Congress in 1915, and was requested to recommend certain further action to the Board at its next meeting.

The Committee on Italian Memorial reported a conference with Sculptor Herbert D. Adams and its intention to submit a final report at the next meeting of the Board.

THE FORUM

Dedicated to the Discussion of Institute Affairs

At the last meeting of the Board of Directors a resolution was adopted recognizing the propriety of permitting, to a limited extent and under the supervision of the Editing Committee, the use to the members of the columns of Section I of the PROCEEDINGS for the expression of their views on topics of current interest.

In accordance therewith, there is established with this issue of the PROCEEDINGS a new department called "The Forum," where will be printed, under the terms of the resolution of the Directors, such communications from members in the form of letters to the membership as are of interest to the membership as a whole.

The opportunity for exchange of views on more or less public topics is greatly to be desired, and it is hoped that THE FORUM may be the means of giving an outlet to ideas, suggestions, criticisms and comments on Institute affairs that have heretofore not had an appropriate place for their expression.

The constitutional amendments which were published in full in the February issue of the PROCEEDINGS, with comments and explanations, have elicited the following letters:

PROPOSED AMENDMENT FOR ADDITIONAL GRADE OF MEMBERSHIP.

To the members of the American Institute of Electrical Engineers.

Gentlemen: The writer has just been informed of the action of the Directors in opening the columns of the PROCEEDINGS to pertinent discussions of matters before the Institute and he has been requested to open up the matter of regarding the membership, in behalf of those few who criticise the proposed constitutional amendments. Because of the hurried preparation of this letter, he wishes here to emphasize the fact that this is no personal controversy, that he has no hostility to the Board, and that he has very high regard for the opinions of the many who do not agree with him. This is a question with two sides. The following considerations seem to the writer to weigh against one feature of the proposal sufficiently to prevent its adoption in the present form. They may appear to some as arguments for the idea in amended shape:

In the first place we should learn something from the experience of the other engineering societies of the world. The term "Fellow" was in use when the American Societies of Civil, Mining, and Mechanical Engineers, the British Institutions of Civil, Mechanical and Electrical Engineers, the Societe des Ingenieurs de France, and no end of smaller bodies, adopted the grades "Member," "Associate Member," "Associate" and "Student" or "Junior," etc. The reasons that then prevailed against "Fellow" are still stronger now, in view of the advisability of keeping the grades in the several societies reasonably uniform in name and requirements. All classes of engineers hope to come before the public, as advisers, more and more and only the very plainest professional titles are to be displayed. The American public has not the veneration for professional titles seen abroad and "Fellow" is likely to arouse amusement or ridicule fatal to the usefulness of some public service. As an instance of this it is interesting to note that "Fellows" of the American Institute of Architects appearing as advisers to the public (as in the recent development of a court house site plan in New York City) seem to quietly drop the official designation for "Members" or "Representatives."

The public evidently does not, at present, realize the distinction between "Members" and "Associate Members" of one society or between the "Fellows' of the American Society of Civil Engineers (an obsolete class of "financial supporters") and of this

Institute. It is desirable that the public should come to have some clear idea of membership standing in all the engineering societies. Multiplying the number of titles encountered hinders rather than helps to this end and uniformity is to be sought in names and practices.

It is said that there is ample precedent for use of the term "Fellow"; some 40 British and 15 American learned and "near-learned" societies are cited, but the cases are hardly parallel. Why should we follow, for instance, the Auctioneer's Institute, Institute of Chartered Accounts, Faculty of Actuaries, Institute of Journalists, Philharmonic Society, College of Organists, Royal Photographic Society, Society of Antiquaries, etc., or the New York, Texas, Indiana, and Southern California Academies, or even The Ornithologists Union, the Entomological, Geological, Zoological, and Astronomical Societies, the Royal College of Physicians, Royal Horticultural Society, etc? The first section of such a list comprises bodies of whose existence the public is ignorant; the second section comprises the truly scientific societies. The first we need not consider. The public expects sound common sense and practical ability in an engineer, whereas it does not in the profound scientist, and may even esteem him the more according to the peculiarity of titles he can append to his name. "Fellow" is fanciful when applied to an engineer and opposed to the impressions of simplicity and practicality. Moreover, before we can seriously consider these precedents we should compile a list of those societies where the term "Fellow" is applied to a secondary or affiliated grade. Time has prevented the writer from making such a list.

What alternative terms are there? The Directors have rejected the nomenclature which would secure uniformity with the other great engineering societies, and probably because of the expected difficulty of securing the consent of the present "Members" to their transfer to new grades of "Member" or "Associate Member" as their records may dictate. Casual examination of the present list of "Members" shows that the affiliations of 30, at most, would indicate the possibility of such a reduction of nominal rank. It would be a selfish and small-minded "Member" who would oppose a transitory reduction in nominal rank if he realized that thereby he was blocking the road to better relations between the whole engineering profession and the public. The present "Associates" should have little objection to being split into "Associates" and "Associate Members" or to paying the moderate increase in dues that seems advisable to the Directors. The writer, among others, believes that the difficulties attendant on the use of "Member," "Associate Member" and "Associate" are not so great but that they can be overcome. He also believes that the membership would not refuse, even at personal sacrifice, to adopt this sort of classification if it were shown that the whole profession and the public would gain thereby.

Very truly yours,

HARRY BARKER.

505 Pearl St., New York City.
Feb. 19, 1912.

To the Members of the American Institute of Electrical Engineers.

Gentlemen: That all of the details relating to the proposed amendments to the constitution of the American Institute of Electrical Engineers will meet instantaneously with universal approval is too much to expect. Moreover, in all conceivable cases where many minor changes must be introduced in order to accomplish a more desirable total result, it is to be expected that certain changes considered individually appear to be unnecessary or even undesirable. In view of the above considerations, it is gratifying to learn that the only objections that have been mentioned in connection with the proposed changes in the A.I.E.E. constitution are ones that were thoroughly discussed by the committee recommending the changes, and were dismissed after each member had been fully convinced that the changes proposed would prove of benefit to the Institute membership as a whole.

The undesirability of retaining the title "Member" for the highest grade of membership will be appreciated at once by any person who compares the requirements for admission to the proposed highest grade with those for the present grade of "Member." As compared with present requirements the proposed requirements are such that a present "Member" desiring to retain his title would be compelled to pay increased dues, or if he preferred to continue to pay the former dues he would be compelled to become, perhaps, an "Associate Member" rather than a "Member." According to the proposed changes that "Member" who wishes to pay the former amount of dues continues as a "Member" and is associated with men having a professional standing closely analogous with a "Member" in other engineering societies.

There may be some word better than "Fellow" to designate the proposed highest grade of membership in the A.I.E.E., but the undersigned has been unable to find it. The unfamiliarity of the word in connection with membership in American engineering societies should not affect its introduction for this purpose, provided its use is justified. Contrary to what is probably too prevalent an opinion among American engineers, the title is employed quite freely to designate the highest grade of membership in a large number of societies in addition to the Royal Society and a few similar organizations, as a reference to the February 1912 PROCEEDINGS of the A.I.E.E. will show. It is apparent, however, that the American Institute of Electrical Engineers will be the first engineering society to adopt the term. In view of the fact that the term is already in common use by other societies, there can be no valid objection to the Institute adopting it for proper purposes. The writer believes that after the members of the Institute have considered all of the correlated facts in the case, they will approve the proposed amendments to the constitution appearing in the February PROCEEDINGS, as explained by the President and unanimously endorsed by the Board of Directors, and that other engineering societies will follow the lead of the American Institute of Electrical Engineers in all departures made from former lines.

A. S. MCALLISTER.

New York, Feb. 20, 1912.

PROPOSED AMENDMENT TO APPOINT THE SECRETARY

To the Membership of the American Institute of Electrical Engineers.

Last year when this same annual and repeatedly defeated amendment was advocated, the writer asked a prominent member of the Board for an explanation of the following point, but did not receive a reply. According to our present constitution the Board already has power to nominate the Secretary, his subsequent election by the members being in effect merely an endorsement of the Board's selection. The proposed amendment therefore differs in that it deprives the members of their privilege to confirm or endorse the Board's selection. If the Board's nomination is satisfactory to the members, it will of course be endorsed, hence why is this amendment put forth annually with such persistence? And why was an explanation of this ignored so discourteously last year? Why does the Board fear or object to this endorsement of the members? Granting that the present Board is entirely innocent of any intentions to make improper use of such irrevocable power, is it safe and wise to give such power to all future Boards, in view of the improper use which might be made of it? It is not in the spirit of modern views on the "referendum and recall."

Why was this feature so interwoven last year with another amendment which was likely to pass, that members could not vote for one independently of the other? In politics this, I believe, is called a "joker" or "rider." It does not seem to be a dignified way of doing in this Institute. It is hoped that the vote on the present amendment is not again to be made inseparable from another one which is likely to be passed.

In the writer's opinion the defeat of this annual amendment last year was an expression of indignation at the way it was put to the members to vote upon.

According to the constitution the Secretary "shall be the executive officer of the Institute." Is it unreasonable for the members to desire to retain their present right to approve or disapprove the Board's selection of such an important officer, even more important in some respects than the President?

As to the voting power of the Secretary, neither he nor the President are supposed to vote unless there is a tie or the necessity for a quorum, hence depriving him of a vote on the Board does not seem to be such an important matter to warrant being brought up annually.

Why does the amendment say that his salary shall be "fixed by the Board" instead of "fixed by the vote of a majority of the entire Board of Directors" as in the present constitution. Why was not attention called to this change? In reprinting the "parts of the constitution affected by the proposed Secretary amendment" in the February PROCEEDINGS, why were the parts which the proposed amendment *omits*, not indicated, so as to make it unnecessary to compare them word for word with the originals?

If the above questions can be explained satisfactorily, the writer, and doubtless many others, will be pleased to vote for the amendment.

President Dunn says "these very policies (of the Board) might be seriously hampered in the event that a Secretary selected by the membership at large were not the right man for the place, the qualification of a candidate for which it would be difficult for many members to judge." The Board at present has the selection of the candidate entirely in its hands, and could even recommend him for nomination; if he is acceptable to the members he will unquestionably be elected. It is the Board and not the members who select him. Is it wise for this Institute to do what "is done by the stockholders in all business corporations"? Is not the Secretary of this Institute an entirely different and much more important official than the secretary of a business corporation?

The proposed amendment for an additional grade of members was urged by the writer twelve years ago in almost the identical form in which it is now offered, including the term "fellow," but it failed to be adopted, and, it seems, was entirely forgotten.

CARL HERING.

Philadelphia, Pa.,
Feb. 21, 1912.

To the Membership of the American Institute of Electrical Engineers:

Mr. Hering's letter appearing in the Forum in this issue of the PROCEEDINGS was not received until the issue had gone to press, but in the desire to live up to the spirit in which the Forum was established and to give the fullest publicity to criticisms of the Institute management, the letter was inserted, together with this letter commenting on some (although not all) of the arguments presented.

The notes and explanations on the proposed Secretary amendment that appear in the February PROCEEDINGS answer some of the questions raised. Mr. Hering argues: "If the Board's nomination is satisfactory to the members, it will, of course, be endorsed, hence why is this amendment put forth annually with such persistence?" It seems that he is under some misapprehension. According to the present constitution, it is the members who move first in making a nomination, and not the Board.

While the Secretary is the executive officer of the Institute, he is not charged with the initiation of its policies nor the general conduct of its business; he is not an executive in the sense that the President of the United States is. The heavy responsibility of conducting affairs the members through the constitution have put upon the shoulders of the Board of Directors; and, in fact, they have put into the constitution, in respect to the Secretary, that he shall be the executive officer of the Institute only " under the direction of the President and the Board of Directors."

In putting the Secretary under the Board, and in charging the Board, and not the Secretary, with the conduct of affairs, the members put their business into the hands of men selected by them for the particular purpose of representing them. If the Board were a group of outsiders instead of being a group of representative elected deputies, Mr. Hering's general contention would be valid. If it should be true that the members of the Board have not properly discharged their function of representatives, the remedy lies with the membership in sending men who would be more faithful. If errors have been made in the choice of representative managers and vice-presidents, of which the Board is composed, they would be liable also in the choice of a Secretary—only the consequences in the latter case would be more serious, since there are twenty-three elected members of the Board and only one Secretary. It cannot be argued that there should be two sets of representatives—the Secretary on the one hand and the Board on the other—possibly at variance with each other.

Experience in the practical conduct of business has led business organizations to choose their secretaries by means of their Boards of Directors, and not by direct election of their stockholders; but it is not only business corporations that have found this experience valuable—the National Electric Light Association, the American Society of Mechanical Engineers, the American Society of Civil Engineers, and a number of other societies, have also found it desirable.

The fundamental fact in the situation is that the Secretary, being put under the direction of the Board by the constitution—and the constitution in this respect unquestionably representing the will of the membership,—should in all respects, including his tenure of office, be responsible to the Board under which he is put, so that the Board in turn may properly discharge its responsibility to the membership. It is needless to say that when a Secretary is responsible to a Board his competence and faithfulness are best judged by that body, and that the mass of the membership, thousands of whom seldom visit the Institute offices, is not in as good a position as the Board to know whether the Secretary is or is not faithfully and competently conducting the business the Board puts into his hands for execution.

It is true that the amendment has been proposed twice before, but it is also true that last year 70.3 per cent of the vote cast was in favor of it in spite of the prevalence of a misunderstanding in respect to its effect upon Mr. Pope; it failed because the constitution requires 75 per cent. The appointment of Mr. Pope last July as Honorary Secretary at full salary removed the misunderstanding, and the Board, believing the amendment to be desired by the membership, in view of the showing of last year's vote and expressions of sentiment during the year, has again put it forward.

The February PROCEEDINGS showed what the new constitution would be if the amendments were adopted. Attention was not called to the omission in one place of the clause affecting the salary of the Secretary because the reappearance of this clause in a different place was duly pointed out by italics. The vote of the Secretary is not an important matter one way or the other; if he should become an appointed officer, the Board would not have the right to elect him a member, and to have him vote would be inconsistent. In the course of a year the Directors expend, in round numbers, $100,000 by such majority vote as is called for by the laws of the State under which the Institute is incorporated. There is no adequate reason why a different kind of majority vote should be required for the salary of the Secretary. The voting of the Board, however, is usually unanimous.

The nearer the Institute comes to be managed on an efficient business basis the greater will be the benefits it can give to its members and the greater will be its influence and prestige.

GANO DUNN.

Feb. 23, 1912.

A. I. E. E. Meeting in New York, February 9, 1912

The two hundred and sixty-eighth meeting of the A.I.E.E. was held in the Engineers Building, New York, Friday evening, February 9, 1912. The meeting was called to order by President Gano Dunn at 8:30 o'clock. President Dunn introduced Professor George F. Sever, the official head of the Institute delegation on the trip to Panama, who had just returned the day before. Professor Sever spoke briefly of the inspection trips made on the Isthmus and the courtesies shown to the Institute party by the American officials and President Arosemena of Panama. (Professor Sever's report on the Panama Convention is printed in Section II of this issue of the PROCEEDINGS.)

President Dunn then introduced the speaker of the evening, Mr. George I. Rhodes, who presented his paper on " A Method of Studying Power Costs with Reference to the Load Curve and Overload Economies." At the close of the reading, President Dunn opened the way to the discussion of the paper, which was participated in by Messrs. H. G. Stott, H. L. Smith, P. M. Lincoln, C. O. Mailloux, Farley Osgood, and George I. Rhodes. At the close of the discussion a vote of thanks was accorded Mr. Rhodes for his able and original paper.

After the close of the discussion President Dunn recommended that the members study carefully the exposition, as given in the February PROCEEDINGS, of the effect of the proposed constitutional amendments establishing a third grade of membership. Earnest consideration of the matter was urged, that the amendments might not fail of passage for lack of the required minimum vote, thirty per cent of the whole membership of the Institute.

The meeting was then adjourned, the members going up to the offices of the Institute on the tenth floor for the social gathering which followed the regular session.

Associates Elected February 9, 1912

ADDINGTON, CHARLES BOYD, Electrician, Northern California Power Co., Cons., Inskip Power House, Paynes Creek, Cal.

ALLNER, FRED A., Assistant Chief Engineer, Pennsylvania Water & Power Co., Room 39 United States Fidelity & Guaranty Bldg., Baltimore, Md.

AMOS, WALTER LAWRENCE, Designing Electrical Engineer, Smith, Kerry & Chace, 551 Confederation Life Bldg.; res., 140 D'Arcy St., Toronto, Ont.

APPLETON, JOHN THOMAS, Designing Engineer, A. C. Engineering Dept., General Electric Co., Schenectady, N. Y.

BACKUS, EDWARD EVANS, Superintendent Telegraph, E. P. & S. W. System, 208 E.P. & S.W. Bldg.; res., 1111 Brown St., El Paso, Texas.

Baker, Harold E., Foreman of Butte Steam Plant and Sub-station, United Missouri River Power Co., Butte, Mont.

Baskervill, George Booth, Jr., Consulting Engineer, McLeod & Baskervill, and Supt., City Light & Water Plant, Macon, Miss.

Batchelder, Charles Clark, Engineering Dept., General Electric Co.; res., 406 Union St., Schenectady, N.Y.

Benson, Elof, Professors' Assistant, Massachusetts Institute of Technology; res., 40 Rutland Sq., Boston, Mass.

Blake, George Barnes, Mississippi River Power Distributing Co.; res., 5961 Plymouth Ave., St. Louis, Mo.

Braconnot, Charles Pandia, General Manager. Compania Cantareira & Viacao Fluminense, Praca 15 de Novembro No. 3, Rio de Janeiro, Brazil.

Chambers, Harry Colpitts, Electrician, Canadian Pacific Railway; res., 2716 5th Ave., W., Vancouver, B. C.

Champreux, Alfred Joseph, Engineer of Transmission Work, Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco, Cal.

Clark, Frank Shaw, Assistant Engineer, Ohio Electric Railway Co.; res., 224 Stanton Ave., Springfield, Ill.

Clark, Ora Allen, Assistant to Electrical Superintendent, General Electric Co., res.; 229 Parkwood Blvd., Schenectady, N. Y.

Cloake, Warren Taylor, Roseburg, Oregon.

Cole, John Melvin, Laboratory Assistant, Bureau of Standards; res., 128 B. Street, N.E., Washington, D.C.

Converse, Clovis Miller, Electrical Engineer, Commercial Dept., St. Paul Gas Light Co.; res., 303 North Snelling Ave., St. Paul, Minn.

Cooke, Milton William, Superintendent of Telephones, Philadelphia Company, Pittsburgh; res., 1212 Oakridge Ave., Brookline, Pittsburgh, Pa.

Coors, William Frederick, Test Man., General Electric Co.; res., 453 McClellan St., Schenectady, N. Y.

Corbaley, Frank Enos, Laboratory Attendant, Electrical Engineering Dept., Leland Stanford, Jr., University, Stanford University, Cal.

Crawford, Thomas, General Manager, Clinton Gas, Electric Light & Coke Co.; res., 532 Kenilworth Court, Clinton, Iowa.

Cummins, Cloyd, Student, General Electric Company; res., 50 Westminster St., Pittsfield, Mass.

Cummins, Lester, Student, General Electric Co.; res., 50 Westminster St., Pittsfield, Mass.

Cureton, James Gustavus, Graduate Student, Allis-Chalmers Co.; res., 403 64th Ave., West Allis, Wis.

Curtiss, Wesley Leonard, Mechanical Engineer, N. Y. C. & H. R. R. Co.; res., 720 West 181st St., New York, N. Y.

Darrin, David, Liability Dept., Ocean Accident & Guarantee Corp., 59 John St.; res., 418 W. 118th Street, New York, N. Y.

De Bijoya Krishna, Block Signalling Dept., East Indian Railway, Allahabad, India.

Dellenbaugh, Frederick Samuel, Jr., Engineer on D. C. Design, Crocker-Wheeler Co., Ampere, N. J.

DeWitt, Stanley Chipman, Assistant Manager, Federal Engineering & Supplies, Ltd., 284 Yonge St., Toronto, Ont.

Dienner, John Astor, Assistant Examiner, United States Patent Office; res., 1700 15th St., Washington, D. C.

Dods, Francis A., General Electric Co., West Lynn; res., 98 Bristol Road, Somerville, Mass.

Doolittle, Harold Lukens, Assistant Engineer, Southern California Edison Co., 329 San Fernando Bldg., Los Angeles, Cal.

Douds, Herman J., Commercial Engineer, J. G. White & Co., 43 Exchange Place; res., 157 West 72nd St., New York, N. Y.

DOUGALL, GEORGE FARRELL, Railway Specialist, General Electric Co., Chicago; res. 240 So. Grove Ave., Oak Park, Ill.

DOW, BENJAMIN WARREN, Assistant Constructing Engineer, Stone & Webster Engg. Corp'n., 147 Milk St., Boston, Mass.

DOWNTON, PERCIVAL GEORGE, Engineer in Sales Dept., Electric Storage Battery Co., Marquette Bldg.; res., 7225 Union Ave., Chicago, Ill.

DRYER, WILLIAM POOLE, Engineer, W. Poole Dryer Co., Ltd., 218 Winch Bldg.; res., 745 Burrard St., Vancouver, B. C.

DU BOIS, WARREN LIVINGSTON, Cadet Engineer, Public Service Electric Co. of New Jersey, Newark; res., 3 Broad St., Freehold, N. J.

EAGAR, GEORGE EVERETT TRAVER, Industrial Control Dept., General Electric Co., Schenectady, N. Y.

ENFURTH, GUS FRED, Electrician, Fort Smith Light & Traction Co.; res., 910 South 17th St., Fort Smith, Ark.

FINKENSIEPER, BENJAMIN WILLIAM, Inspector, Western Electric Co., 463 West St., New York; res., 346 Vernon Ave., Brooklyn, N. Y.

FULLER, LEONARD FRANKLIN, Assistant Instructor in Electrical Engineering, Cornell University; res., 702 E. Buffalo St., Ithaca, N. Y.

GILMAN, MAURICE CLARK, Power Salesman, Toronto Electric Light Co., Ltd., 12 Adelaide St., East; res., 48 Churchill Ave., Toronto, Ont.

GRIER, BAXTER R., General Foreman, Electrical Dept., Isthmian Canal Commission, Gatun, C. Z.

GRONEN, HAMILTON FRANK, Chief Engineer, Nisqually Power Plant; res., 4314 North Mullen St., Tacoma, Wash.

GULLEY, CHARLES LESLIE, Sales Engineer, Northern Electric & Mfg. Co., Ltd., 112 Bay St.; res., 328 Broadview Ave., Toronto, Ont.

HALDEMAN, HAROLD WATSON, 389 West End Ave., New York City.

HARBINSON, THOMPSON DEAN, Manager of Electrical Dept., Macan Jr. Company; res., 60 North Third St., Easton, Pa.

HARDY, CHESTER HARVEY, Instructor in Electrical Engineering, Washington University; res., 6101 Washington Ave., St. Louis, Mo.

HARRIS, AMBROSE REEVES, Asst. Director, Edison Storage Battery Laboratory, West Orange, N. J.

HARRIS, WILLIAM CRIGHTON, Electrical Engineer, Day & Zimmerman, 608 Chestnut St.; res., 5108 Hazel Ave., Philadelphia, Pa.

HEITMANN, ALBERT HENRY, Instructor in Electrical Engineering, Ohio State University; res., 615 East Rich St., Columbus, Ohio.

HIRAYAMA, TSUYOSHI, 35 North Wendell Ave., Schenectady, N. Y.

HOUGH, JOHN H., Commercial Engineer, General Electric Co., 30 Church St., New York; res., 299 Vanderbilt Ave., Brooklyn, N. Y.

HOWE, HENRY LAWRENCE, JR., Rochester Railway & Light Co., 34 Clinton Ave., N., Rochester, N. Y.

HUEY, RAY SIMEON, Assistant Superintendent, Universal Portland Cement Co., Buffington, Ind.; res. 7146 Paxton Ave., Chicago, Ill.

INOUYE, TOSHIO, Electrical Engineer, Imperial Government Railways, Tokyo; res., Kuzuha, Moji, Japan.

JACKSON, GLENN, Power Station Operator, Otsego & Herkimer Railroad Co., and Hartwick Power Co., Hartwick, N. Y.

JOHNSTON WILLIAM ROBERT, Industrial & Power Division, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

JONES, DAVID WILLIAM, Graduate Student, Rose Polytechnic Institute; res., 911 N. 8th St., Terre Haute, Ind.

JONES, EDWARD CROSLEY, Engineer on D. C. Design, Crocker-Wheeler Co., Ampere, N. J.; res., 550 Park Ave., New York, N. Y.

KAI, HIDEO, Student, Imperial University; res., 26 Sekiguchi Dai St., Tokyo, Japan.

Kasson, Charles LeBaron, Head of Electrical Testing Division, Boston Edison Electric Illuminating Co., 39 Boylston St., Boston, Mass.

King, John Russell, Solicitor, Sales Department, Seattle Electric Co.; res., 220 14th Ave., N., Seattle, Wash.

Kyle, Elmer Langham, Experimental Engineer, Philadelphia Electric Co., 122 Arch St.; res., 1212 S. 45th St., Philadelphia, Pa.

Langley, Philip Gendron, Electrical Engineer, General Electric Co.; res., 12 Haigh Ave., Schenectady, N. Y.

Liversidge, Horace P., Asst. Supt. Station Construction, Philadelphia ElectricCo., 10th & Chestnut Sts.; res., 5643 Cedar Ave., Philadelphia, Pa.

Lovell, Alfred Henry, Instructor in Electrical Engineering, University of Michigan; res., 604 E. Jefferson St., Ann Arbor, Mich.

Mahan, James Steel, Electrical Inspector, Electrical Inspection Bureau, 76 West Monroe St., Chicago, Ill.

Markle, David Lloyd, Instructor in Electrical Engineering, Pennsylvania State College, State College, Pa.

Matthews, John Vincent, Experimental Engineer, Philadelphia Electric Co., 122 Arch St.; res., 1715 Erie Ave., Philadelphia, Pa.

McIndoo, Otis Wilmer, Plant Department, New York Telephone Co.; res., 406 James St., Syracuse, N. Y.

Metcalf, Earle S., Student, Bryant & Stratton College; res., 229 Carolina St., Buffalo, N. Y.

Miess, Fred, Construction Foreman, Engg. Dept., General Electric Co., Provident Bank Bldg., Cincinnati, Ohio.

Miller, George Smith, Student in Electrical Engineering, Bryant & Stratton College; res., 116 Plymouth Ave., Buffalo, N. Y.

Montgomery, Stafford, Production Engineer, Piece-Work Dept., Western Electric Co., Hawthorne, Ill.

Murphy, William Edward, District Manager, Allis-Chalmers-Bullock, Ltd.; res., 393 Graham St., Winnipeg, Man.

Neill, Ralph Douglas, Operator, Western Canada Power Co., Ruskin, B. C.

Nixdorff, Samuel Purdy, Consulting Engineering Dept., General Electric Co.; res., 104 Jay St., Schenectady, N. Y.

Palmer, Robert, Research Engineer, General Electric Co.; res., Ballston Road, Schenectady, N. Y.

Pengilly, Joseph Hill, Electrical Engineer, 385½ Mill St., Portland, Ore.

Petty, Edwin W., Electrical Engineer, 4134 Berkeley Ave., Chicago, Ill.

Plumb, Maurice William, Engineering Apprentice, Canadian Westinghouse Co., Ltd.; res., 36 Grant Ave., Hamilton, Ont.

Pratt, Francis C., Assistant to Vice-President, General Electric Co.; res., 16 Washington Ave., Schenectady, N. Y.

Rankin, Fred Jones, Instructor of Electrical Engineering, Colorado Agricultural College, Fort Collins, Colo.

Rhodes, Sam R., Instructor, University of North Dakota, University, N. D.

Richmond, Lester Chart, Contracting Electrician, Hassalo Engineering Co., 1 North First St.; res., 446½ Larrabee St., Portland, Ore.

Ruede, Eugene Maxwell, Illuminating Engineer, De Cew Company, Ltd., 616 Portage Ave.; res., 328 Carlton St., Winnipeg, Man.

Sevin, Emil Charles, Electrical Engineer, Grain Storage Construction Co.; res., 77 North Ashland Ave., Buffalo, N. Y.

Seymour, Earl R., Student Engineer, General Electric Co., Schenectady, N. Y.

Shroyer, J. Leland, Electrical Engineer, Laboratory, General Electric Co., Pittsfield, Mass.

Sievers, Ernest John Joseph, Cadet Engineer, Public Service Electric Co., Hudson Division; res., 65 Willow Ave., Hoboken, N. J.

Smith, Walter Vernon, Operator, Bay Shore Sub-station, Sierra & San Francisco Power Co., 85 Second St.; res., 682 3rd Vve., San Francisco, Cal.

Solitro, Almerico, Electrical Engineer, General Electric Co.; res., 780 Albany St., Schenectady, N. Y.

Sparling, Morley Whitehead, Superintendent of Power House, Sidney Electric Power Co., Trenton, Ont.

Sprague, Frank Desmond, Civil Engineer, with Frank J. Sprague, 165 Broadway; res., 40 East 57th St., New York, N. Y.

Stanley, Leonard Lovejoy, Electrical Engineer, Transformer Engineering Dept., General Electric Co., Pittsfield, Mass.

Stott, James, Inspector of Electricity & Gas, Dominion Government; res., 712 Pender St., W., Vancouver, B. C.

Stude, Alphonse Jerome, Special Apprentice, Erie Railroad Co., Hornell, N. Y.

Taber, Frank Sylvesta, General Contractor, Nowata, Okla.

Thomas, Gilbert Maxey, Electrical Engineer, J. G. White & Co., San Francisco; res., 2214 Union St., Berkeley, Cal.

Van Gravesande, Johan Willem Storm, Draftsman, Power Construction Co., Shelburne Falls, Mass.

Vogel, Leopold Julius, Foreman of Testing, Ideal Electric & Mfg. Co.; res., 652 West 3rd St., Mansfield, Ohio.

Waggoner, David Gray, Cadet Engineer, Denver Gas & Electric Light Co.; res., 1101 East Colfax Ave., Denver, Colo.

Wendell, Chester Snell, Cadet Engineer, Public Service Corporation of New Jersey, 1 Gamewell St., Hackensack, N. J.

Wheelwright, Barton, Draftsman, Grand Trunk Railway; res., 114 Dowling Ave., Toronto, Ont.

Wiggins, Stanley Boardman, Electrical Engineer, Muralt & Co., 274 Engineering Bldg., Ann Arbor, Mich.

Williamson, George, Electrical Engineer on D. C. Design, Crocker-Wheeler Co., Ampere; res., 122 N. 17th St., East Orange, N. J.

Williamson, Victor Browning, Engineering Assistant, New York Telephone Co., 26 Cortlandt St., New York, N. Y.

Willis, Sydney, Switch Gear Designer, British Westinghouse Elec. Mfg. Co., Manchester, Eng.

Winchester, Laurence Somerby, Station Electrician, Lowell Electric Light Corporation, Lowell; res., Reading, Mass.

Wopat, John William, Electrical Engineer, New York Telephone Co., 547 Clinton Ave., Brooklyn; res., Hicksville, L. I.

Zimmerman, Frank LeRoy, Sales Engineer, Westinghouse Electric & Mfg. Co., 27 Woodward Ave.; res., 25 Bagg St., Detroit, Mich.

Associates Transferred on February 9, 1912

The following Associates were transferred to the grade of Member in the Institute at the meeting of the Board of Directors held on February 9, 1912:

Albert M. Allen, Consulting Engineer, Cleveland, Ohio.

Charles W. PenDell, Engineer, Contract Department, North Shore Electric Company, Chicago, Ill.

Arthur L. Mudge, Electrical Engineer in charge of Construction, Smith, Kerry and Chase, Toronto, Ont.

William C. Bauer, Head of Electrical Engineering Department, Northwestern University, Evanston, Ill.

Walter E. Holland, Chief Electrical Engineer, Edison Storage Battery Company, Orange, N. J.

Samuel Insull, President, Commonwealth Edison Company, Chicago, Ill.

Recommended for Transfer February 6, 1912

The following Associates were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on February 6, 1912. Any objection to the transfer of any of these Associates should be filed at once with the Secretary.

T. P. **Strickland**, Chief Assistant Electrical Engineer, N. S. W. Government Railways, Sydney, N. S. W.

Edward E. Clement. Telephone Engineer, Patent Attorney and Patent Expert, Washington, D. C.

Vladimir Karapetoff, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

R. **Parks Ruckes**, Consulting Engineer, Charlotte, N. C.

John H. Morecroft, Assistant Professor of Electrical Engineering, Columbia University, New York.

H. M. **Gassman**, Electrical Engineer, Tennessee Coal, Iron and Railroad Company, Birmingham, Ala.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before March 25, 1912.

11120 Magnus, H. C., West Lynn, Mass.
11121 Klockars, C. P., Hartford, Conn.
11122 Moore, J. T., Jr., Macon, Ga.
11123 Carlson, T., Almena, Kan.
11124 Segar, R. L., Westerly, R. I.
11125 Cottman, L. W., Baltimore, Md.
11126 Zimmer, A. R., Toronto, Ont.
11127 Buchanan, E. C., Spokane, Wash.
11128 Lunan, H. J. S., Sorel, Que.
11129 Kennedy, G. M., Lansford, Pa.
11130 Turnbull, T. L., Calgary, Alta.
11131 Thompson, J. H. Jr., Seattle, Wash.
11132 Geiger, W. H., Hackensack, N.J.
11133 Williams, G. F., Brookline, Mass.
11134 Schlarbaum, A., Galt, Ont.
11135 Strong, F. P., Sandford, N. C.
11136 Davies, G. A., Shawinigan Falls, Que.
11137 Carr, L., 3d., West Lynn, Mass.
11138 Arana, V. M., Lima, Peru.
11139 Vestal, M., No. Yakima, Wash.
11140 Uhl, W. F., Boston, Mass.
11141 Robison, A. R., Butte, Mont.
11142 Hoyt, R. S., New York, N. Y.
11143 Wade, R. S., Buffalo, N. Y.
11144 Haydon, G. S., Wabana, Newfoundland.
11145 Szilas, O., Budapest, Hung.
11146 Nichols, H.E., Schenectady, N.Y.
11147 Fernald, B. G., Pittsburgh, Pa.
11148 Helms, H., New York, N. Y.
11149 Nash, C. A., Schenectady, N. Y.
11150 Procter, J. H., College Sta. Tex.
11151 Egan, F. D., Midland, Pa.
11152 Waller, A. E., Mt. Vernon, N.Y.
11153 Edgar, W. H., Portland, Me.
11154 Gallivan, J. D., Corozal, C. Z.
11155 Greenawalt, A. E., Gibson, Ind.
11156 Delafield, C. E., Boston, Mass.
11157 Black, W. A., Indianapolis, Ind.
11158 Dudley, W., Pittsburgh, Pa.
11159 Goldsmith, C., Charlestown, Mass.
11160 Gray, G. F., Schenectady, N. Y.
11161 Gray, R. C., Philadelphia, Pa.
11162 Hallock, M.O., West Lynn, Mass.
11163 Herbst, W. B., Pittsburgh, Pa.
11164 Lewis, F. E., Indianapolis, Ind.
11165 Phelps, R. L., San Francisco, Cal.
11166 Shearer, H. F., Toronto, Ont.
11167 Sherborne, F.G., Vancouver, B.C.
11168 Sylvester, W. V., Seattle, Wash.
11169 Wilson, E. J., Lynn, Mass.
11170 Thompson, G. E., Antwerp, Bel.
11171 Francis, H. L., Mexico, D. F.
11172 Baldwin, J. H., New York, N. Y.
11173 Barnes, A. J., Halifax, N. S.
11174 Barton, T. F., New York, N. Y.
11175 Camprubi, J., Buenos Aires, A.R.
11176 Cole, W. H., Boston, Mass.
11177 Curtis, G. S., Paterson, N. J.
11178 Glines, E. S., Boston, Mass.
11179 Hoskins, H.A., Schenectady, N.Y.
11180 Johanny, M. G., Mansfield, O.
11181 Jones, E. G., Terre Haute, Ind.
11182 Logan, H. B., New York, N. Y.
11183 Lusby, F. J., Atlanta, Ga.
11184 Lyall, A. V., New York, N. Y.
11185 MacDermot, S.G., Montreal, Que.
11186 Morphet, F. H., Philadelphia, Pa.
11187 Palmer, C. E., Toronto, Ont.
11188 Valentines, G., New York, N. Y.
11189 Drees, C. J., Little Rock, Ark.
11190 Sutherland, F. D., Detroit, Mich.
11191 Payne, F. T., Reno, Nev.
11192 Kittredge, C., Detroit, Mich.
11193 Rader, W. E., Cleveland, O.
11194 Patton, R. C., Providence, R. I.

11195 Linden, H. E., San Francisco, Cal.
11196 Kummer, L., Pittsfield, Mass.
11197 Bettison, W. R., Fishers Island, N. Y.
11198 Dequine, L. E., Madison, Wis.
11199 Donner, W. E., Grand Is., Neb.
11200 Kehoe, A. H., Brooklyn, N. Y.
11201 Beebee, R. A., Palo Alto, Cal.
11202 Brueggeman, F., Chicago, Ill.
11203 Beers, C. W., Wilkes Barre, Pa.
11204 Davis, J. W., Terre Haute, Ind.
11205 Kerr, B. W., Pittsburgh, Pa.
11206 Desbaillets, C. J., Montreal, Que.
11207 Wallace, R. B., St. Paul, Minn.
11208 Hicks, L. R., Fall River, Mass.
11209 Davis, B. D., Louisville, Ky.
11210 Converse, M., Cleveland, O.
11211 Betts, H., Rio de Janeiro, Brazil.

Total, 92.

Students Enrolled February 9, 1912

4911 Uhl, H. C., Rose Polytechnic Inst.
4912 Elliot, J. A., Univ. of Toronto.
4913 Drew, H. A., Armour Inst. Tech.
4914 Fairbank, P. W., Tufts College.
4915 Lloyd, W. E., Jr., Lafayette Coll.
4916 Cornwell, H. V., Cornell Univ.
4917 De Garmo, L. H., Cornell, Univ.
4918 Maxfield, C. D., Cornell, Univ.
4919 Shamberger, J.P.L., Cornell Univ.
4920 Churchill, L. B., Syracuse Univ.
4921 Bissmeyer, A. H., Univ. of Cinn.
4922 Lange, M., Univ. of Cincinnati.
4923 Smith, W. L., Univ. of Cinn.
4924 Wiseman, R. J., Mass. Inst. Tech.
4925 Cocklin, H. S., Penna. State Coll.
4926 Gerard, H. J. A., Ohio State Univ.
4927 Hazen, C. P., Columbia Univ.
4928 Clouser, G. L., Stevens Inst. Tech.
4929 Bowers, J. H., Ohio State Univ.
4930 Whitaker, D. A., Armour I. T.
4931 Hobart, E. A., Ohio State Univ.
4932 Abbott, W. H., Ohio State Univ.
4933 Higgins, R., Ohio State Univ.
4934 Manning, H. J., Ohio State Univ.
4935 Menke, O. H., Ohio State Univ.
4936 Mangold, E. G., Ohio State Univ.
4937 Wyatt, F. D., Ohio State Univ.
4938 Welsh, C. M., Ohio State Univ.
4939 Popp, C. M., Ohio State Univ.
4940 Miller, R. O., Ohio State Univ.
4941 Gordon, C. S., Ohio State Univ.
4942 Raney, E. C., Ohio State Univ.
4943 Shannon, J. W., Ohio State Univ.
4944 McDaniel, C. H., Ohio State Univ.
4945 Geib, J. R., Ohio State Univ.
4946 Moody, R. M., Ohio State Univ.
4947 Higgins, R., Ohio State Univ.
4948 Fraser, A. C., Univ. of Colorado.
4949 Greenwood, A. L., Univ. of Colo.
4950 Mueller, C. A., Univ. of Colorado.
4951 Moulton, V. C., Univ. of Colo.
4952 Twiss, R. H., Univ. of Colorado.
4953 Leonard, L. R., Univ. of Colo.
4954 Etheridge, H. L., Tufts College.
4955 Quennell, A. W., Tufts College.
4956 Patten, F. H., Tufts College.
4957 Manguin, R. L., Tex. A.&M. Col.
4958 Deming, G. E., Univ. of Penn.
4959 Dilworth, T. B., Univ. of Penn.
4960 Markland, A. R., Univ. of Penn.
4961 Wilkinson, K. L., Univ. of Penn.
4962 Fisher, C. W., Univ. of Penn.
4963 Dunphy, C. A., Wash. State Coll.
4964 Varner, W. R., Oregon Agri. Coll.
4965 Pinkerton, C. S., Univ. of Cinn.
4966 Jefferson, W. H., Univ. of Cinn.
4967 Doerschuk, H. M., Univ. of Wis.
4968 Green, R. E., Univ. of Toronto.
4969 Morgan, R. C., New Hamp. Coll.
4970 Jennings, E. B., New Hamp. Coll.
4971 Perrin, W. J., Univ. of Toronto.
4972 Hay, W. O., Jr., Lafayette Coll.
4973 Griesinger, F. S., Ohio State Univ.
4974 Fishel, J. E., Lafayette College.
4975 Jungk, H. G., Case Sch. Science.
4976 Maue, F. W., Lafayette College.

Total, 66.

Addresses Wanted

Name	Former address
H. H. Hess,	Hellertown, Pa.
Wm. A. Hirt,	Evanston, Ill.
J. R. Klippelt,	Kirksville, Mo.
F. C. Newell, Jr.,	38 Vesey St., New York, N. Y.
R. C. Norman,	Lockport, Ill.
F. W. Randall,	Ellenville, N. Y.
J. W. Rutherford,	283 Summit Ave., Jersey City, N. J.
Peter V. Schupp,	Minneapolis, Minn.
E. J. Simon,	230 Riverside Drive, New York, N. Y.
James P. Starrett,	Lynn, Mass.
C. A. Tozer,	Spencerport, N. Y.

F. W. Up de Graff,	Pachuca, Hidalgo, Mexico.
J. S. VanBylevelt,	Dresden, Germany.
T. Philip Walker,	36 Burton Ave., Montreal, Que.
G. M. Willis,	25 E. Walton Place, Chicago, Ill.

Members or Associates who can give information that may assist in obtaining any of these addresses are requested to communicate with the Secretary of the Institute.

Past Section Meetings

BALTIMORE

The Baltimore Section held a meeting on February 2, in the Physical Laboratory of the Johns Hopkins University, at which Dr. J. B. Whitehead presided. Mr. Ralph D. Mershon of New York gave an interesting and instructive paper on "The Rudiments of Corporate Finance." Mr. Mershon treated of the various kinds of securities used in financing corporations, and illustrated in a very apt way the advantages of corporate ownership over partnerships. He also brought out the salient advantages of holding companies. Forty-five members were present.

CLEVELAND

The regular meeting of the Cleveland Section was replaced by an inspection trip on January 26 to the new Lake Shore Station of the Cleveland Electric Illuminating Company, at the foot of East 70th St.

The station is planned on the unit system throughout. Coal is dumped at the track hopper, screened, crushed and elevated, and then distributed by belt conveyors to bins above the boilers. The boiler plant consists of a battery of nine 500 nominal boiler horse power Stirling boilers per unit, with chain grate stokers and an auxiliary coking grate ahead of the main grate. The feed pumps are of the rotary turbine driven type.

The main generating equipment consists at present of two 14,000 kw. vertical type Curtis turbines, and by the middle of the year two 9,000 kw. machines will be installed, making a total of 46,000 kw. The present building, approximately 260 ft. square, is designed to accommodate six 14,000 kw. units. Current is generated and transmitted directly through underground conduits at 11,000 volts, Y connected with provision for grounding the neutral.

Each generating unit is supplied with its own auxiliary apparatus. A slow speed reciprocating engine drives a tandem connected air pump and also a rotary circulating pump of the centrifugal type. Oil for the step bearings, etc., is supplied by a high and low pressure reciprocating pump. The exciter machines are: two 200 kw. motor driven generators, one 75 kw. turbine driven, and a storage battery, 100 kw. at 1 hr. rate or 200 kw. at 20 minute rate, floating on the exciter line. The main generator switches and exciter switches are operated from a gallery in the generating station. All selector switches and high tension switches are located in a separate three-story switch house situated 500 feet away from the main station. All load dispatching is done at this switching station.

This trip proved to be very interesting and instructive, and was deeply appreciated by all of the 150 members and visitors who attended.

DETROIT-ANN ARBOR

The regular monthly meeting of the Detroit-Ann Arbor Section was held January 20, in the New Engineering Building, Ann Arbor. Professor C. L. de Muralt presided at the meeting, which was attended by 40 members and students. The meeting was preceded by the annual Ann Arbor dinner, at the Cutting Cafe. The paper of the evening, "Ocular Considerations in Illuminating Engineering," was presented by Mr. A. S. Sweet, commercial engineer of the Holophane Company. Mr. Sweet paid particular attention to the questions of street lighting, and the color of interior walls.

FORT WAYNE

The regular January meeting of the Fort Wayne Section was held on the 18th of the month at the Fort Wayne Commercial Club. Mr. E. A. Wagner presided. The resignation of Mr. J. V. Hunter, local secretary, who was obliged to give up his office by reason of removal from the city, was received and accepted. Resolutions were unanimously adopted, expressing the sincerest regret at Mr. Hunter's resignation, thanking him for his work for the Section, and wishing him the utmost success. Mr. A. B. Morrison, Jr., was elected to fill the office of secretary.

Mr. Walter Kent presented a paper on "Engineering Specifications," bringing out clearly the features essential in a specification that is to secure the purchaser exactly what his requirements demand, and yet not handicap the manufacturer. The discussion was spirited and representative, members engaged in engineering, commercial and sales work taking part, among them Messrs. Nordstrom, Ganter, Behan, Webber, Wagner and Morrison.

The meeting was preceded by an informal dinner in honor of Mr. Hunter, the retiring secretary. Adjournment was early, to allow the members to attend a Civic Improvement meeting held at the club the same evening.

INDIANAPOLIS-LAFAYETTE

The Indianapolis-Lafayette Section held its organization meeting on Feb. 1, 1912, in Indianapolis. Preceding the meeting, 15 members met at the Glenalba Cafe for dinner. Mr. G. B. Schley, chairman of the committee on by-laws appointed at the preliminary organization meeting, reported the results of the committee's work. The by-laws were adopted and the following officers elected: chairman, Mr. O. S. More, Indianapolis; vice-chairman, Professor C. Francis Harding, Purdue University, Lafayette; secretary, Mr. Charles A. Tripp, Indianapolis; executive committee, Mr. Charles R. Moore, Purdue University, Lafayette, and Mr. G. B. Schley, Indianapolis. Mr. More reported that he had secured six applications for membership in the Institute since the authorization for the establishment of the new Section had been granted. The Section is planning to hold its first regular meeting in March and will make an especial effort to have this meeting attractive to all interested in electrical engineering work.

ITHACA

One of the most successful banquets of the Ithaca Section was held in Sibley Dome on January 10. About 128 men were present. Before the banquet a reception was held in the Dome, during which most of those attending availed themselves of the opportunity of meeting the guests of honor, who were Mr. Gano Dunn, president of the American Institute of Electrical Engineers and vice-president of J. G. White and Company, and Mr. W. O. Wiley, secretary of Wiley and Company, publishers, New York.

Professor E. L. Nichols, of the physics department of Cornell University, acted as toastmaster at the banquet. He first called on Mr. Wiley, who responded with a few well chosen remarks. Professor Nichols then called on Mr. Dunn, who was the principal speaker of the evening. Mr. Dunn's subject was "The Kind of Man Who Makes a Successful Engineer," and his speech was an inspiration to everyone present. It was in the main part a plea for greater intensity and force in the execution of the tasks confronting engineers rather than for a higher degree of scholarship. He distinguished two components in an engineer's worth: one component of knowledge, and one of force and judgment in the execution of his work, which latter he designated as the dynamic component. The component of knowledge he characterized as the inspiration to acquire and promote knowledge for its own sake, and the so-called dynamic component as the inspiration to make knowledge serviceable in executing the work of the engineer. Mr. Dunn also spoke of the importance, to every man in a responsible and executive position, of a speaking and writing command of good, fluent, forcible English. In closing he brought out a geometrical analogy to the two character components of scholastic attainments and dynamic force of which he had been speaking.

Los Angeles

The regular monthly meeting of the Los Angeles Section was held on January 23, in the music hall, Blanchard Building, Mr. O. H. Ensign presiding. There were present 52 members and visitors. Two papers were presented, one "Comments on Show Window Lighting," by E. Y. Porter, and the other "Practical Illumination," by F. B. Lewis. Mr. Lewis illustrated his paper by means of lantern slides and a contrivance to show the reflection of light by walls of different colors. Messrs A. J. Kennedy, O. H. Ensign, F. S. Mills, A. W. Nye and R. H. Manahan took part in the discussion of the papers. Prof. Nye illustrated his discussion with lantern slides showing the effect of complementary colors on the eye. Prof. R. W. Sorenson displayed slides showing the lighting schemes in various cities.

Lynn

The members of the Lynn Section met on January 10, in the West Lynn Odd Fellows Hall, with Mr. E. E. Boyer in the chair. After a brief business session, the chairman introduced the speaker of the evening, Mr. Harry N. Atwood, who gave a very interesting talk on "Aeronautics," and told of many of his personal experiences. After his talk, Mr. Atwood answered questions on aeroplaning. The lecture was enjoyed by 20 Institute members and 200 enrolled students.

At the Lynn Section meeting in the same place on January 25, Mr. E. E. Boyer presiding, 190 members and students listened to a paper read by Mr. L. T. Robinson, of the standardizing laboratory of the General Electric Company, Schenectady, on "Electrical Measuring Instruments from the Standpoint of the User." Mr. Robinson went into his subject very thoroughly and explained why different types of instruments should be selected for different classes of work.

Milwaukee

The January meeting of the Milwaukee Section A.I.E.E. and the Engineers Society of Milwaukee was held in the Plankinton House on January 10. About 85 members and guests were present. Mr. F. W. Ells presided. Mr. C. N. Duffy, auditor of the Milwaukee Electric Railway and Light Company, presented a paper on "Electric Utilities."

The paper dealt separately with the railway, and light and power branches of the Milwaukee service. Tables of statistics of United States railways were given, and similar comparative tables of the local system. The various costs were tabulated and itemized showing the distribution of gross revenue. Statistics of cost per ride and per mile were given and comparison was made of these rates with those in the municipally operated Glasgow Tramways, and the municipally regulated Cleveland Railways. Statistics of reduced cost of transportation and of increased speed of traffic were given in comparison with the conditions 20 years ago, and some of the benefits to the community were reduced to a basis of the yearly saving per passenger. The figures submitted were used in connection with operating methods in a strong plea for private ownership and operation of street railways under competent commission supervision, as opposed to municipal operation.

Under the subject of the light and power division the investment, capacity and profits of the local plant were compared with the average for the United

States. Tables of distribution of total expense under the various items of "fixed" and "variable" expenses were given and explained and a careful analysis was made of the cost of service for different load factors. From this the principles of the "demand rate" were deduced and the equity of the rate explained. The plans of the local company for extending its service and improving its load factor were explained, and the mutual benefits to consumer and producer were emphasized.

Mr. Duffy next considered the proposed plans for a municipal lighting plant and the cost per lamp, including operating expense contingencies, loss of taxes, depreciation and interest on bonds and mortgages, was shown to be a minimum of $86.57 per year on the basis of $35.75 per lamp year as operating expense. These figures were contrasted with the $65 per lamp per year now paid by the city as a valid argument against the proposed municipal plant, even without any consideration of the quality of the service expected.

In the discussion following the paper the advantages and disadvantages of different types of "Pay As you Enter" cars were debated, with regard to improvement in handling the service and cutting down the operating expenses. The single "motorman-conductor" against the present two man arrangement was proposed as cutting down the operating expenses, 40 per cent of which are for wages. Attention was called to the advantage of combining street car service with central station power supply in increasing the load factor during the day, thereby reducing considerably the fixed charges of the combined equipment. This raised the question whether it would be possible with such combined system to properly separate charges against the railway and the lighting service. Attention was called to the low rates for electric service in Switzerland. This is accounted for primarily by the abundance of water power. It was maintained that these low rates are partially offset by increased taxation, which could be reduced if the water power rates were properly adjusted and equitable taxation of water power companies was maintained, which would then throw the burden on the actual consumer of electric power instead of charging part of it to the general public.

Many other questions regarding rate making of public service utilities, franchises, and other rights and duties of public service utilities were discussed. The discussion was very animated throughout and the meeting adjourned at a late hour.

PHILADELPHIA

The Philadelphia Section held a joint meeting with the electrical section of the Franklin Institute at the Hall of the Franklin Institute on January 17, which was preceded by an informal dinner at the Bingham Hotel. Mr. H. C. Snook presided. Mr. Hoadley, as chairman of a committee which had been appointed for that purpose, presented a resolution in reference to the death of Mr. C. I. Young, which, on motion of Mr. Walton Clark, was adopted. (This resolution appeared on page 76 of Section I, February PROCEEDINGS).

The paper of the evening, entitled "Research Laboratory Notes," was presented by Dr. W. R. Whitney, director of the research laboratory of the General Electric Company, Schenectady. It was discussed by Messrs. Hoadley, Flanders, Snook, J. M. Dodge, F. B. Gilbreth and Dr. Barnes. The meeting was attended by 105 members and visitors.

PITTSFIELD

The Pittsfield Section met at the Hotel Wendell on January 18, to hear a paper by Mr. Frederick Darlington, of the Westinghouse Electric and Manufacturing Company. Mr. Darlington spoke on "Central Station Electric Power for Railroad Operation," and was followed with close attention by the engineers present. His remarks were not confined to detailed discussion of any particular plants, but covered the general problem of the use of central station power for railroads. Following the address, a short discussion was held in which the following took part: Messrs. William Stanley, W. J. Wooldridge, H W. Tobey, L. Kummer, S. E. Greene, Joseph Franz and M. T. McGovern.

Mr. William Stanley presided at the meeting. Preceding the lecture fourteen engineers attended the dinner in honor of Mr. Darlington.

The meeting of the Pittsfield Section on February 1, attended by 40 members and students, was presided over by Mr. W. C. Smith. The members unanimously approved the proposed trip of inspection through the Hoosac Tunnel electrification on February 22. Mr. W. J. Wooldridge of the local plant of the General Electric Company gave a most interesting and instructive talk on the " Manufacture and Treatment of Sheet Steel." Mr. Wooldridge gave a history of the development of alloy steel for electrical work and described the various electrical and mechanical properties of different grades of steel now in general use for electrical purposes. A short discussion took place following the address.

This was the first meeting of the Section at which a local man was the speaker, and it is planned to have local speakers every four weeks during the remainder of the active season.

PORTLAND, ORE.

The regular monthly meeting of the Portland Section, attended by 35 members and visitors, was held January 16, in the assembly hall of the Electric Building, with Mr. F. D. Weber in the chair. The principal business transacted consisted in hearing a report covering work that had been done toward obtaining papers for presentation at the meeting of the Institute to be held in Portland, April 16–20, inclusive. As ten or twelve very good papers have been promised and practically assured, the Portland Section is quite confident of holding a very successful meeting. Mr. Weber appointed the chairmen of a number of committees, which will have charge of the various arrangements for the meeting. The library committee made a further report in regard to plans for the equipment of the new library building.

The paper of the evening, " When Does it Pay to Develop Water Power?" was presented by Mr. J. R. Thompson, consulting engineer. This paper was practical in its nature and dealt particularly with Pacific Coast conditions, which Mr. Thompson was well fitted to discuss on account of his long residence and work on the Pacific Coast.

SAN FRANCISCO

The San Francisco Section held its regular meeting on January 26, in the Home Telephone Building. Mr. S. B. Charters, Jr., was in the chair. The meeting was attended by 68 members and guests. Mr. O. A. Falch of the Sierra and San Francisco Power Company, assisted by Mr. H. W. Crozier of Sanderson and Porter, presented an interesting paper on " High Tension Transmission Lines," with especial reference to the Stanislaus installation. Mr. Crozier had a number of lantern slides which showed very vividly the complete installation, from power house to substation, including the different phases of construction of the line itself. Preceding the meeting 15 or 20 members dined informally at the Old Poodle Dog Restaurant.

The San Francisco Section gave an informal dinner at the same place on February 3, in honor of Past-president Bion J. Arnold and his assistant, Mr. J. R. Bibbins, to express the conviction of the members of the Section that the city of San Francisco had been fortunate in securing the services of Mr. Arnold to take charge of the study of the city's traction problem. Mr. Arnold in his address described briefly the manner in which the transactions between the municipalities and the traction companies had been handled in Chicago and Cleveland. His time was so limited that he was unable to go into any details regarding the local situation. The toastmaster was Mr. H. A. Lardner, and others who spoke briefly were Messrs. J. R. Bibbins, G. C. Holberton and J. G. DeRemer.

SCHENECTADY

The one hundred and fourth meeting of the Schenectady Section was held in Red Men's Hall on January 23, Mr. E. B. Merriam, section chairman, presiding. After calling the meeting to order, the chairman presented Mr. E. W. Rice, Jr., who, after a few remarks, introduced Prof. Elihu Thomson, of the General Electric Company, who presented an interesting paper on " A Hunt for a Great Meteor and Its Lessons," which he illustrated by a number of lantern slides. There were about 600 members and guests, including about 100 ladies, present at this meeting.

On January 31, the Schenectady Section met in Silliman Hall, Union College, Prof. O. J. Ferguson presiding. This meeting was the first of a series proposed by the discussion meetings committee, intended to be informal gatherings at which all attending would be expected to participate in the discussion. In the absence of Mr. Gus A. Maier, who had intended to give an abstract of his recent paper on " Methods of Varying the Speed of Alternating Current Motors " (read at the Institute meeting in New York, December 8), Mr. Maier's paper was read in abstract by Mr. Campbell Macmillan of the induction motor department of the General Electric Company. Mr. W. C. K. Altes then gave a very lucid explanation of the characteristics of single-phase series, compensated series and repulsion motors. A general discussion was participated in by Messrs. Macmillan, M. O. Spring, L. Lustig, H. M. Hobart, C. Lichtenberg and others, who drew attention to the sparking limitations of alternating current motors, the method of changing speed by changing the number of poles, some cases in which alternating current motors are better than direct current motors, the limit in sizes of three-phase commutator motors, and the characteristics of Winter-Eichberg motors. About 60 Section members and guests were present.

The one hundred and sixth meeting of the Schenectady Section was held in Red Men's Hall on February 6, with Mr. J. B. Taylor in the chair. About 200 members and guests were present. The speaker of the evening was Professor D. F. Comstock of the department of physics of the Massachusetts Institute of Technology, who read a very interesting paper, " A Chapter in the Modern Theory of Electricity," paying particular attention to the very latest electronic theories and giving all of the known physical properties of electrons. Professor Comstock described a number of the exceedingly interesting and ingenious experiments of Rutherford and Milliken which have been directly responsible for the recent rapid growth of our knowledge on this subject. He also briefly outlined the new German light-energy theory which advances the hypothesis that light, and probably electricity and all other forms of energy, are discontinuous phenomena due to the displacement of small particles of matter and not to etheric vibrations. Following Professor Comstock's paper, Messrs. Milton Franklin, W. R. Whitney, G. H. Hill, E. J. Cheney and R. B. Tenney, Jr., discussed it and asked a number of questions to which Professor Comstock later returned answers.

SEATTLE

The regular monthly meeting of the Seattle Section was held on December

16, in the Chamber of Commerce Central Building. Mr. Hawes was chosen chairman *pro tempore.* Mr. E. F. Whitney gave an abstract of the paper on "Engineering Specifications" by Mr. Frank F. Fowle, published in the September, 1911, PROCEEDINGS, after which a general discussion was entered upon by Messrs. Ross, Hawes, Lindsay, King, Cooley, Tirrell and Whitney.

The January meeting of the Seattle Section was held on the 18th of the month in the Central Building. The annual election of officers was held, resulting in the choice of Mr. J. D. Ross as chairman and Mr. M. T. Crawford as secretary. A letter from Mr. H. T. Edgar, manager of the Seattle Electric Company, was read, offering the Section the use of the assembly room in the company's office building for the regular meetings. The Section voted, however, to continue the present arrangement of sharing the assembly room and reading room in the Central Building with the Pacific Northwest Society of Engineers, as this makes for closer relations between the societies.

A paper was presented by Mr. W. C. Wagner of the faculty of the University of Washington on the use of electricity in coal mining operations, containing very interesting data on the performance of the various electrically driven features of a large mine. The paper was discussed by Messrs. Harisberger, King, Moore, Lindsay, Crawford and others.

ST. LOUIS

At the regular meeting of the St. Louis Section held on January 10, in the rooms of the Engineers Club, Mr. James E. Allison, chief engineer of the Public Service Commission of St. Louis, gave a very interesting paper on the "Control of Public Utilities."

The purpose and work of a public service commission were explained in some detail. As an illustration of the work that was required of such a commission, Mr. Allison said that an experienced engineer might go into a central station and in a week or a month's time be able to give a fairly good opinion as to the value of the property. This, however, would not do for a public service commission, whose work must be such as to stand the closest scrutiny of the courts where facts and not opinions must be considered. Several different theories on which valuations of public utilities have been based, were explained. These are:

1. Original cost theory.
2. Cost of reproduction, new.
3. Cost of duplicating service.
4. Continuous property theory.

This last theory allows a certain fixed return on the investment and a surplus at any time is deducted from capitalization, while a deficit is capitalized. The terms wear and tear, inadequacy and obsolescence, were defined in their relation to property valuation. The short time franchise was declared to be against the interests of the public. The indeterminate franchise, or perpetual franchise with option to buy at a reasonable valuation, was stated to be the best for both public and investor. The discussion of the paper was participated in by Messrs. Morey, Greensfelder, VonMaur, Spoehrer, and Humphrey. Mr. H. H. Humphrey presided at the meeting, which was attended by 43 members and visitors.

TOLEDO

The regular monthly meeting of the Toledo Section on February 2, was held at the Toledo Commerce Club, with Mr. George E. Kirk in the chair. Thirty-one members and guests attended. Professor C. L. de Muralt of the University of Michigan gave a lecture on "Electric Power Transmission at High Pressures," illustrated with lantern slides. Professor de Muralt introduced his subject by giving some of the elementary calculations for determining the size and voltage of a transmission line. He proceeded to describe his practical experience in constructing the 110,000 volt transmission line of the Hydroelectric Power Commission of Ontario, showing some of the views taken during the construction of the line, and the various methods employed in erecting the steel towers. He also spoke of the unexpected difficulties that were encountered in the construction—things that could not be determined theoretically. Following the paper, an interesting discussion was participated in by many of those present.

URBANA

At the meeting of the Urbana Section on January 12, at the University of Illinois, Mr. T. D. Yensen, assistant in the Illinois Engineering Experiment Station, gave an illustrated lecture on the Panama Canal. Mr. Yensen, who recently returned from the Isthmus, prefaced his talk by a short historical sketch of the Canal from the first conception of such an undertaking to the time the United States Government took over the holdings of the French company. He gave great credit to the French and the skilful engineering work they had done and stated that the greatest achievement of the American engineers was the successful solving of the problem of sanitation. The lecture was unusually entertaining and instructive, as Mr. Yensen presented a large number of views taken by himself. He gave his hearers a very clear understanding of the construction to date and described many interesting details of the work.

Approximately 300 were present. Mr. E. H. Waldo presided. After the lecture a short business meeting was held and Professor Morgan Brooks and Dr. E. J. Berg were elected members of the executive committee.

On January 19, the Urbana Section and the Electrical Engineering Society of the University of Illinois held a joint smoker at which more than 200 engineers and students were present. After refreshments and several vaudeville features, President R. S. Leese of the society introduced Dr. E. J. Berg, of the University of Illinois, and Professor Morgan Brooks, vice-president of the Institute, who spoke briefly. The smoker was so successful that both societies agreed to make it an annual affair.

VANCOUVER

At the regular monthly meeting of the Vancouver Section, held on December 1, 1911, at the Travellers Hotel, Mr. H. N. Keifer read a paper on "Inductive Interference on Telephone Lines Paralleling High Tension Power Transmission Lines." Mr. F. D. Nims presided, and 26 members and visitors attended the meeting.

The regular meeting of the Vancouver Section held on January 5, at the Carlton Cafe, with Mr. F. D. Nims in the chair, was attended by 28 members and visitors. Messrs. R. F. Hayward and F. D. Nims gave an informal talk on the equipment and operation of the Mexican Light and Power Company's systems at Necaxa and in the City of Mexico. Mr. Hayward was general manager and Mr. Nims electrical engineer of that company at the time of the consolidation of the various local companies and the installation and starting up of the hydroelectric plant at Necaxa, and they were able to give some interesting details regarding the engineering difficulties encountered and the means taken to overcome them.

A regular meeting of the Vancouver Section was held on February 2, at the Carlton Cafe, 21 members and six visitors being present. Mr. F. D. Nims presided. An informal dinner was served, after which the members listened to a very interesting paper on "Types of Multiple Unit Control in General Use on American Electric Roads," by Mr. John R. Read. The paper was very thorough in its treatment of the subject. In the discussion which followed, Mr. J. B. Ingersoll, electrical engineer for the British Columbia Electric Railway Company, Vancouver, who had had previous experience in multiple unit work with the Spokane and Inland Empire Railway Company, furnished some details of operating experiences, and Mr. D. P. Roberts, inspector of electrical energy for the Provincial Government, brought up some interesting points in connection with three-phase railway work.

Past Branch Meetings

A. AND M. COLLEGE OF TEXAS

The Agricultural and Mechanical College of Texas Branch was reorganized for the year 1911-1912 on October 11, 1911, and the following officers were elected: chairman, C. E. Greene; secretary, M. L. Johnson; program committee, H. G. Eppler, G. H. Hemphill, and G. W. Ashford. Professor F. C. Bolton addressed the members on the aims and purposes of the Institute, and urged that as many students as possible become members of the Branch.

The first regular meeting for the year was held on November 2. The following papers were presented: "Transformer Oils," by A. B. Collins; "Street Lighting," by A. Sherley; "High Potential Transmission," by Professor Lear. Twenty members and visitors attended the meeting.

The second regular meeting was held on January 18. Mr. J. H. Proctor gave a talk on the apprenticeship course at the Westinghouse Electric and Manufacturing Company's works.

The third meeting was held on January 24. Mr. B. D. Atwell gave a description of the Diesel engine, which was followed by a paper on "Line Shaft Drive and Individual Motor Drive in Machine Shops," by Mr. G. W. Ashford. The Institute paper by Mr. W. B. Jackson on "Advantages of Unified Electric Systems Covering Large Territories" was reviewed and discussed by C. E. Greene.

UNIVERSITY OF ARKANSAS

The University of Arkansas Branch held a meeting at Fayetteville on January 16, with Mr. F. H. Oneal in the chair. Mr. C. W. Paul read the first paper of the evening, on cables for feeder circuits. Professor B. N. Wilson then gave a lecture on the efficiency of prime movers, comparing reciprocating steam engines, steam turbines and gas engines. The paper was discussed by Professor Gladson and others.

ARMOUR INSTITUTE OF TECHNOLOGY

The Armour Institute Branch held a meeting on January 10, in Chapin Hall, with an attendance of 32. Professor E. H. Freeman presided. Mr. C. E. Freeman, consulting engineer, addressed the meeting on "Financial and Engineering Features of Hydroelectric Development." He spoke briefly on the beginnings and financing of a proposed development, and outlined the engineering report, dividing it into three parts covering the physical, engineering and financial features of the development. Discussing in detail each item, Mr. Freeman laid stress on the value of accuracy and good judgment. He then outlined the next step in the development, the drawing up of plans and specifications by the engineer.

BUCKNELL UNIVERSITY

A meeting of the Bucknell University Branch was held on January 17 with Mr. H. S. Sweet in the chair. Mr. H. E. Bastian read a short paper on "The Theory of Recording Wattmeters, Their Testing, Calibrating and Adjusting." The paper was illustrated by the actual testing and adjusting of a number of different meters in the laboratory.

UNIVERSITY OF COLORADO

The regular meeting of the University of Colorado Branch was held on January 17, with Mr. L. R. Leonard presiding. The speaker of the evening was Mr. L. R. Handley, '08, of the Carstarphen Electrical Company, Denver. Mr. Handley's talk dealt with the design and construction of switchboards. He discussed the various materials used, comparing them as to ease of handling, appearance, cost, and facility of drilling and erecting.

IOWA STATE COLLEGE

The Iowa State College Branch met for the election of officers on January 24, with Professor A. Shane, chairman, presiding. Thirty-four members and students attended. The following officers were elected: chairman, Professor F. A. Fish; secretary-treasurer, F. A. Robbins; executive committee, Professor H. C. Bartholomew, F. B. Jackson, H. A. Frommelt; social committee, F. W. Hanson, V. N. Friedman, J. J. Shoemaker. The following membership committee was appointed: L. C. Stang, P. H. Koolish, F. W. Hanson.

The meeting of the Iowa State College Branch on February 7, Professor Fish presiding, had for its subject the recent inspection trip of the senior electrical students. Mr. F. W. Hanson compared and contrasted the power plants of the Commonwealth Edison Company, the hydroelectric plant at Joliet, Ill., and the gas engine driven plant at Gary, Ind. Mr. D. J. McDonough discussed the various railway plants and substations visited, and Mr. E. P. Gibson described the works of the Western Electric Company at Hawthorne and the Allis-Chalmers Company at Milwaukee. Thirty-eight members and students attended the meeting.

UNIVERSITY OF KANSAS

A meeting of the University of Kansas Branch was held on January 24, with Mr. L. A. Baldwin in the chair. Thirty-two members and students heard Dr. James Naismith of the department of physical training of the University, who gave a description of "first aid" treatment and artificial respiration, describing various devices used for the latter. Mr. W. F. Price spoke on the present status of the incandescent lamp industry, and Mr. H. H. Campion reviewed the recent developments in powerful turbines.

The University of Kansas Branch met on February 7, Mr. L. A. Baldwin presiding. Messrs. W. D. Thompson and D. K. Crawford reported on current literature. Mr. A. A. Thompson of the Kansas City branch of the General Electric Company gave a description of the mercury arc rectifier. He presented a clear explanation of the principle of operation of the rectifier and compared it with motor-generator sets with regard to efficiency and cost.

UNIVERSITY OF MAINE

The University of Maine Branch held its regular meeting on January 18. Professor W. H. Herschel of the mechanical department gave an interesting talk on "Water Power Development." Thirty-five attended the meeting.

The meeting of the University of Maine Branch on January 24 was addressed by Mr. James P. King, Maine '11, now instructor in the electrical laboratory of the Massachusetts Institute of Technology, on the subject of "High Tension Measurements."

UNIVERSITY OF MISSOURI

The meeting of the University of Missouri Branch on January 8 was addressed by Dr. Schlundt of the chemistry department, who was sent on an expedition to Yellowstone Park in 1896 with Dr. Moore by the United States Geological Survey to make determinations of radio-activity. Their results were published in the *U. S. G. S. Bulletin*, No. 395. Dr. Schlundt described the methods used and difficulties encountered in their work, and told of some of the picturesque characters among the early explorers in that region.

New Hampshire College

The second meeting of the New Hampshire College Branch was held on January 8. Mr. P. F. Goodrum, chief equipment man of the American Telephone and Telegraph Company of Boston gave a lecture on " The Telephone." As an introduction the speaker pointed out the superiority of the telephone over the railroad as an annihilator of distance and explained the chief difficulties (leakage, resistance, inductance and capacity) encountered in long distance transmission, as well as the methods and appliances at present used to eliminate each one. Mr. Goodrum discussed the problem constantly before the telephone engineer as to how much expense should be permitted in the system, since a large outlay would cause a high toll rate, whereas a small outlay would cause poor service. As an example of the work involved in installing an underground cable system Mr. Goodrum spoke of the one at present under construction between Boston and Washington. Views taken during the construction of the portion between Providence and New Haven were thrown on the screen. The results of a sleet storm were illustrated by photographs taken during the winter of 1909 when the American Telephone and Telegraph Company suffered heavily from interference with the telephone traffic. Early and present telephone exchanges, the process of connecting one subscriber with another, as well as simplex, composite and phantom circuits, were considered by the speaker. Insulators, wires, cables, drops, plugs, jacks and other equipment used in telephone traffic were explained and were open to inspection at the close of the lecture.

The third meeting of the New Hampshire College Branch on January 22 was addressed by Mr. Edgar G. Scott, of Boston, on " Some Power Problems in General Engineering." Following this, Mr. N. J. Neall, consulting electrical engineer, of Boston, gave a short address on " The Advantages of Becoming a Member of the A.I.E.E." Mr. Scott prefaced his talk by outlining the work of an apprentice in one of the large electrical companies. He showed wherein it was up to the apprentice to make good in every department and the great necessity of using diplomacy when he was desirous of changing to another branch of the work. Much stress was put on the fact that every problem in practice must be solved correctly, good intentions not being sufficient to get a man by as oft times happens in college.

The main points in the design of a power station were discussed as follows: The first question is not only how much power will be required for present needs, but also how much is expected to be needed in the future. The location of the station depends upon three things: the proximity to power demands, the facility for obtaining coal, and the source of water supply. Having decided upon the location of the station preliminary drawings are to be made of approximately what is to be desired in the plant, the location of the machines being such as to have the shortest possible piping, care being taken not to have things crowded. The question of equipment is one of price as against efficiency; first cost should not determine the kind of equipment. Having determined the kind of equipment, the final drawings should be made, remembering that the detail work should not be a copy of the preliminary drawings. In conclusion Mr. Scott showed a few slides illustrating the typical central station.

N. C. College of A. and M. Arts

The North Carolina College Branch held a meeting on January 24. The recent paper by Mr. Gus. A. Maier on " Methods of Varying the Speed of Alternating Current Motors " was presented in abstract by Mr. William Hand Browne. A general discussion followed.

OHIO STATE UNIVERSITY

The meeting of the Ohio State University Branch on January 11 was addressed by Mr. Rolph of the Holophane Company, Newark, Ohio, whose subject was "The Design of Holophane Globes and Reflectors." The meeting was attended by 44 persons.

OREGON AGRICULTURAL COLLEGE

At the meeting of the Oregon Agricultural College Branch on January 4, Mr. A. M. Jepperson presented a paper on "Starting Induction Motors," and Mr. W. R. Varner read a paper on "Voltage Regulation." After the program the plans for the Electrical Show were discussed.

UNIVERSITY OF OREGON

The regular meeting of the University of Oregon Branch was held on January 9. Dr. W. P. Boynton talked on "Bridge Methods of Precision," describing and demonstrating the use of the Kelvin and percentage bridges. Mr. F. F. Northrop demonstrated the use of the Evershed bridge, measuring the resistance of concrete piers, insulation, etc. Professor C. N. Converse presented an illustrated paper on "The Modern Steam Turbine."

PURDUE UNIVERSITY

The regular meeting of the Purdue University Branch on December 5, 1911, was attended by 95 persons. The meeting was occupied with a symposium on recent developments in traction. The subjects and speakers were: "The Mallet Type Steam Locomotive," Mr. F. E. Laramore, '12; "Electrification of the New York, New Haven and Hartford Railroad," Mr. W. L. Cremers, '12; "Superheaters on Locomotives," Mr. F. X. Thale, '12; "Comparison of Steam and Electric Locomotives," Mr. T. Titus, '12.

At the meeting of the Purdue University Branch on January 9, Mr. J. Peterson, formerly a machinist mate on board the *U. S. S. Nebraska*, gave an illustrated lecture on "Electricity in the Navy." The speaker traced the development of electrical applications on board a man-of-war from the first installation of a small generator for lighting on the *U.S.S. Trenton* to the modern plants of turbo-generators aggregating 1000 kw. or more, with the auxiliary equipment of lights and motors for hoisting, training guns and turrets, steering, and every other purpose for which mechanical power on board ship is needed. The lecture was profusely illustrated by many photographs of equipment and appliances.

THROOP POLYTECHNIC INSTITUTE

The Throop Polytechnic Institute Branch met on December 23, 1911. The new chairman, Mr. F. C. Miller, gave a short talk on the work of the Branch. Mr. Ray Catland then gave an illustrated lecture on "Methods Used in Mining Gold and the Amalgamation of the Ore."

At the monthly meeting of the Throop Branch on January 28, Mr. C. W. Koiner, general manager of the Pasadena Municipal Lighting Plant, read a paper on "Municipal Electric Lighting Plants," giving some valuable data in connection with municipal ownership.

UNIVERSITY OF VERMONT

The meeting of the University of Vermont Branch on February 12 was occupied with a general discussion of Vermont's water power development by Mr. H. P. Hudson, '02, of the General Electric Company.

YALE UNIVERSITY

The Yale University Branch held its fifth meeting on January 19, in the Mason Engineering Laboratory, New Haven. Mr. D. Seltzer, '12 S, read a paper on "Liquid Insulating Materials." Following this Mr. S. A. Griswold, '12 S, spoke on "Copper versus Aluminum for Transmission," illustrating several of his points with experiments.

The sixth meeting of the Yale University Branch was held on February 2. Mr. C. R. Beardsley, formerly with the General Electric Company, now with the United Illuminating Company, of Bridgeport, Conn., gave an illustrated lecture on "The Commercial Application of Induction Motors." Mr. Beardsley explained briefly the theory of the induction motor, then gave an account of his experience with motors of this type in their industrial application. His slides showed several of the different types of machines in use at the present time.

Personal

Mr. J. E. King, formerly with the Westinghouse Electric and Manufacturing Company, has taken a position in the operating department of the Nevada-California Power Company, at Goldfield, Nevada.

Mr. Carl Hering was honored by his Alma Mater, the University of Pennsylvania, on February 22, with the bestowal of the honorary title of Doctor of Sciences. Doctor Hering already had the degree of M.E. from the same university.

Mr. Harve R. Stuart has resigned his position in the engineering department of the Westinghouse Electric and Manufacturing Company and is now in the engineering department of the Robbins and Myers Company, of Springfield, Ohio.

Mr. S. A. Staege, consulting hydroelectric engineer of Watertown, N. Y., has taken into partnership Mr. R. H. Bennett of New York. The firm name is now Staege and Bennett. The firm will continue to make a specialty of hydroelectric and steam engineering.

Mr. P. G. Burton, heretofore located in Washington, D. C., as plant superintendent of the Washington division of the Chesapeake and Potomac Telephone Company, has been appointed engineer of that company, with offices at 108 East Lexington Street, Baltimore, Maryland.

Mr. Arthur Floyd Norcross, who for some time past has been general manager of the Engineering Supervision Company, of New York, at the last meeting of the board of directors was elected vice-president and director of the company. The rest of the board of directors remains as before.

Mr. St. J. R. Marshall recently resigned his position in the government sales office of the Westinghouse Electric and Manufacturing Company, and has opened an office in Washington, D. C., 713 Colorado Building, as district sales manager for the Ridgway Dynamo and Engine Company, of Ridgway, Pa., manufacturers of steam engines, and electrical generators and motors, under the Thompson-Ryan patents.

Mr. H. B. Stabler, formerly secretary of the Washington, D. C., Section of the A.I.E.E., and associated with the Chesapeake and Potomac Telephone Company as plant engineer of the Washington division, has been appointed equipment engineer of the recently organized engineering department. Mr. Stabler's office will be at 108 East Lexington Street, Baltimore.

Mr. Ivan E. Hanssen, formerly of the engineering department of the General Electric Company and of the Westinghouse Electric and Manufacturing Company, has gone into partnership with Mr. H. Martin under the firm name "Elektrodrift," with offices in Kristiania, Norway, and in Stockholm, Sweden. The firm will engage in consulting work. During the last two years Mr. Hanssen has been engaged in electric railway work in Norway and Switzerland.

Obituary

Mr. Haynes Lloyd Hart, of the Westchester Lighting Company, New Rochelle, N. Y., died suddenly on January 4, 1912.

Mr. Hart was born at Oswego, N. Y., in 1883. He prepared for college at the Auburn, N. Y., Academic High School, and received the degree of M.E. from Sibley College of Cornell University in 1907. Following his graduation, Mr. Hart was engaged in work with the City Engineer of Auburn, as engineer of bridge erection with F. K. Bennett former division engineer of the Lehigh Valley Railroad, and was in charge of an electrical installation in Binghamton, N. Y. In 1909 he became a cadet engineer with the Westchester Lighting Company, at Mount Vernon, N. Y. On December 16, 1909, Mr. Hart was elected an Associate of the Institute.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Electric Railway Association. Proceedings 1911. Accountant's Association: American Association, Claim Agents Association, Engineering Association and Transportation and Traffic Associations. (5 Vols.). New York, 1911. (Gift of Association.)

American Institute of Electrical Engineers. Yearbook, 1912. New York, 1912.

Annuaire des Chemins de Fer et des Tramways. 26th Année. 1911. (Purchase.)

Bureau des Longitudes. Annuaire pour L'an 1912. Paris, 1912. (Gift of Gauthier-Villars.)

Ciencias Pedagogicas y Filosofia. Tomo II. (Congreso Cientifico (I° Pan-American) Santiago de Chile, 1911. (Gift of Congreso Cientifico, etc.)

Cornell University. Librarian's Report. 1910–11. n.p. n.d. (Gift of Cornell University.)

Les Courants Alternatifs de Haute Fréquence. By A. Charbonneau Paris, 1911. (Purchase.)

Degradation of Accumulative Energy. Paper read before South Wales Institute of Engineers. n.p. n.d. (Gift of South Wales Institute of Engineers.)

Domestic Sanitary Engineering and Plumbing. By F. W. Raynes. New York, 1909. (Purchase.)

Electrical Age. Vol. 38. New York, 1907. (Purchase.)

Electricity. Vol. 15. London, 1901. (Purchase.)

L'Electrification des Grandes Lignes de Chemins de Fer. By J. Signorel. Paris, 1911. (Purchase.)

Elektromotorische Antriebe für die Praxis bearbeitet. By B. Jacobi. München, 1910 (Purchase.)

Engineering as a Vocation. By Ernest McCullough. New York, D. Williams Co., 1911. (Gift of Publishers.)

Beginning with a short history of the engineering profession and giving the definition of an engineer as given by various authorities, the author proceeds to take up engineering as a vocation, describing the education of the engineer, the value of a technical education, and discusses fully the commercial side of the engineer's profession. One of the titles of his chapters is, for instance, "How to Hunt and Hold a Job." It would seem to me that all engineers might read this book with great interest and that its perusal would broaden their point of view.
W. P. C.

Fabrikation der Gummidrähte und Kabel. By M. Wachter. Berlin, 1911. (Purchase.)

Die Hydraulischen Turbinen. (2 Vols.) By Gustav Ziehn. Strelitz, n.d. (Purchase.)

L'Impianto Idroelettrico del Cellina seguito da uno Studio sui Sifoni Autolivellatori Gregotti. By Emilio Gerosa. Trieste, 1911. (Gift of author.)

International Catalogue of Scientific Literature: Ninth Annual Issue. C. Physics. London, 1911. (Gift of E. D. Adams.)

Italy. Ministero di Agricoltura, Industria e Commercio Statistica degli Impianti Elettrici attivati od Ampliati in Italia nel Decennio 1899-1908. Roma, 1911. (Gift of Ministero di Agricultura.)

Journal Telegraphique. Vol. 25. Berne, 1901. (Purchase.)

Laboratory Problems in Physics. By F. T. Jones and R. R. Tatnall. New York, Macmillan Company, 1912. Price, $.50 net.

This small manual is typical of those now in use in the high schools in this country in study of physics. It gives specific directions for performing physical experiments and specific directions for recording results of those experiments. W. P. C.

Lehrbuch der kosmischen Physik. By S. A. Arrhenius. Leipzig, 1903. (Purchase.)

Life and Life Work of Charles Benjamin Dudley. Memorial volume. Philadelphia, n.d. (Gift of American Society for Testing Materials, Executive Committee.)

Light Railway and Tramway Journal. Diary, 1912. London, 1912. (Exchange.)

Maryland. Public Service Commission. Report, 1911. Baltimore, 1912. (Gift of Maryland Public Service Commission.)

Modern Brickmaking. By Alfred B. Searle. London, 1911. (Purchase.)

New Jersey Board of Public Utility Commissioners.

——In the Matter of the Application of the Eastern Telephone and Telegraph Company to Issue Its Eight Year Collateral Trust Notes and in the matter of the Application of the Interstate Telephone and Telegraph Company of New Jersey to issue its five per cent, thirty year, first and refunding mortgage Gold Bonds. Dismissal of Petitions, Jan. 26, 1912. n.p., n.d. (Gift of New Jersey Public Utility Commissioners.)

——In the matter of the Minimum Charge for Power exacted by Electric Companies. Memorandum, Jan. 16, 1912. n.p. n.d. (Gift of New Jersey Public Utility Commissioners.)

——In Re Investigation as to Justice and Reasonableness of Rates of Lambertville Gas Light Company for Gas. Memorandum and Order. Nov. 8, 1911. n.p. n.d. (Gift of New Jersey Utility Commissioners.)

New York State Public Service Commission, Second District Annual Report, 5th. Albany, 1912. (Exchange.)

Osterreichischer Ingenieur und Architektenverein. Jahrbuch, 1912. Wien, 1911. (Exchange.)

Recherches sur les Propriétés Electriques des Alliages d'Aluminium. By W. Broniewski. Paris, 1911. (Purchase.)

Répertoire des Industries Gaz et Electricité. 1911. Paris, 1911. (Purchase.)

Scientific Management and Railroads. By L. D. Brandeis. New York, Engineering Magazine, 1912. (Purchase.)

Smithsonian Institution. Annual Report, 1910. Washington, 1911. (Gift.)

Standard Dictionary of the English Language. New York, Funk & Wagnalls, Co., 1912. (Purchase.)

Statistica degli Impianti Elettrici Attivati od Ampliati in Italia nel Decennio, 1899–1908. Roma, 1911. (Gift of Ministero di Agricoltura, Industria e Commercio.)

Taschenbuch für Mathematiker und Physiker. 2. Jahrgang. 1911. Leipzig, 1911. (Purchase.)

Technique de la Houille Blanche et des Transports d'Energie Electrique. Vols. 1–2. By E. Pacoret. Paris, 1911. (Purchase.)

La Technique Pratique des Courants Alternatifs. By G. Sartori. 2 Vols. Paris, 1909–10. (Purchase.)

Telephony. By S. G. McMeen and K. B. Miller. Chicago, 1912. (Gift of American School of Correspondence.)

Vergleichende Untersuchungen uber den Engler'schen, Redwood'schen und Saybolt'schen Zähigkeirsmesser. By W. Meissner. n.p. n.d. (Exchange.)

Gift of L. Zehnder.

Bemerkung zu der dritten Mittheilung des Hr. Braun: Ueber Deformations-ströme. (Abdruck aus den Annalen der Physik u. Chemie, 1889, bd. XXXVIII.)

Beseitigung der ungeheuren Antennentürme bei der drahtlosen Telegraphie Eine objektive Darstellung der Hertzschen Versuche über Strahlen Elektrischer Kraft durch Wechselströme. (Separatabdruck aus den Annalen der Physik, Band. 33, 1910). Leipzig, n.d.

Geheimhaltung drahtloser Telegramme. Berlin, 1912.

2. Zur objektiven Darstellung der Hertzschen Versuche uber Strahlen elektrischer Kraft durch Gleichströme. (Separat abdruck aus den Annalen der Physik, Band. 33, 1910). Leipzig, n.d.

3. Nachtrag zur Demonstration der Lecherschen elektrischen Drahtwellen. (Separat abdruck aus den Annalen der Physik, Band. 33, 1910). Leipzig, n.d.

Ueber den Einfluss des Druckes auf die Brechungs-exponenten von Wasser, Schwefelkohlenstoff, Benzol, Aethyläther und einigen Alkoholen. By W. C. Rontgen u. L. Zehnder. (Separat abdruch aus den Annalen der Physik u. Chemie, Band. XLIV, 1891.) Leipzig, n.d.

Ueber die Reflexion und die Resonanz der Hertz'schen ekectrischen Schwingungen (Separat abdruck aus den Annalen der Physik u. Chemie, Band. 49, 1893.) Leipzig, n.d.

Ueber elliptische polarisirte Strahlen elektrischer Kraft und über die elektrische Resonanz. (Separat abdruck aus Berichte der Naturforschenden Gesellschaft zu Freiberg, i. B., Band. IX, Pt. 2.)

Ueber Gasentladungen Kathodenstrahlen und Röntgenstrahlen. (Sonder abdruck aus der Naturwissenschaftlichen Rundschau. Jahrgang. XIII, 1898, nr. 38, 39). n.p. n.d.

Uber neue Wirkungen von Kathodenstrahlen und Lichtstrahlen. (Sonder abdruck aus den Verhandlungen der Deutschen Physikalischen Gesellschaft, V. Jahrgang nr. 1.) Braunschweig, 1903.

Versuche mit Strahlen electrischer Kraft: einfachste objective darstellung derselben. (Separat abdruck aus den Annalen der Physik und Chemie, Band. 52, 1894.) Leipzig, n.d.

Trade Catalogues.

Emerson Electric Mfg. Co., St. Louis, Mo. Emerson fans for alternating and direct current. 64 pp.

Ferro Machine & Foundry Co., Cleveland, Ohio.

——Marine engines and equipment. 48 pp.

General Electric Co., Schenectady, N.Y.

——Bull. No. 4888—Cast grid rheostats. 7 pp.

——Bull. No. 4893—Automatic time switch for alternating current, and direct current. 4 pp.

——Bull. No. 4896—High voltage core type transformers. 9 pp.

——Bull. No. 4903—Isolated and small plant, direct current switchboards. 15 pp.

——Bull. No. 4905—Small plant alternating current switchboards. 16 pp.

——Index to Bulletins, Nov. 1911. 8 pp.

Ohio Brass Co., Mansfield, O. O. B. Bulletin, Sept.-Oct. 1911 and Jan. 1912, giving short announcements on electric railway and mine haulage equipment. 48 pp.

Pettingell-Andrews Co., Boston, Mass. Juice—January 1912, published for the information of the company's customers and giving live

information about electrical goods. 17 pp.

Simplex Construction Co., New York,

——Simplex system of concrete piling. 96 pp.

Trump Mfg. Co., Springfield, O. 1912 Catalogue of "Trump" turbines. 48 pp.

UNITED ENGINEERING SOCIETY

Geschafts-Bericht der Deutschen Buchdrucker Berufs-Genossenschaft uber das Rechnungsjahr 1910. Frankfurt an Main, n.d. (Donor unknown.)

Iowa Railroad Commissioners. Annual Report, 33d, 1910. Des Moines, 1910. (Gift of American Electric Railway Association.)

Virginia State Corporation Commission. Annual Report, 8th, 1910. Richmond, 1911.

——Appendix to Annual Report, 8th, 1910. Richmond, 1911. (Gift of T. C. Martin.)

Wisconsin Railroad Commission. Opinions and Decisions. Volume IV. Madison, 1910. (Gift of American Electric Railway Association.)

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

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Revised to March 1, 1912.

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Revised to March 1, 1912.

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Term expires July 31, 1912.

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Term expires July 31, 1913.

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Term expires July 31, 1912.

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Term expires July 31, 1912.

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Revised to March 1, 1912.

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LIST OF SECTIONS.

Revised to March 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Atlanta Jan. 19, '04	A. M. Schoen.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston Feb. 13, '03	William L. Hooper.	G. A. Rodenbaeck, 84 State St., Boston, Mass.
Chicago 1893	J. G. Wray.	
Cleveland Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne Aug. 14, '08	E. A. Wagner.	A. B. Morrison, 817 Nelson Street, Ft. Wayne, Ind.
Indianapolis-Lafayette Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles May 19, '08	O. H. Ensign.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Madison Jan 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Lynn Aug 22, '11	E. E. Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass.
Mexico Dec. 13, '07	W. H. Fiske.	H. S. Foley, Apartado 124 Bis., Mexico, D. F.
Milwaukee Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota Apr. 7, '02	Chas. L. Pillsbury.	Leo H. Cooper, 805 Metropolitan Life Bldg., Minneapolis, Minn.
Philadelphia Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg Oct. 13, '02	K. C. Randall.	E. L. Farrar, G. E. Co., Oliver Bldg., Pittsburgh, Pa.
Pittsfield Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore May 18, '09	F. D. Weber.	H. R. Wakeman, 604 Electric Building, Portland, Ore.
San Francisco Dec. 23, '04	S. B. Charters.	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady Jan 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle Jan. 19, '04	J. D. Ross.	M. T. Crawford, Seattle-Tacoma Power Co., Seattle, Wash.
St. Louis Jan. 14, '03	George W. Lamke.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo.
Toledo June 3, '07	George E Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto Sept. 30, '03	A. L Mudge.	Valentine Boyd, 212 King St , West, Toronto, Ont.
Urbana Nov. 25, '02	E. H Waldo.	F G Willson, University of Illinois, Urbana, Ill.
Vancouver Aug. 22, '11	F. D. Nims.	E. M Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D. C. Apr. 9, '03	Earl Wheeler.	H. C. Eddy, Interstate Commerce Commission, Washington, D. C.

Total, 28.

LIST OF BRANCHES.

Revised to March 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	C. E. Greene.	M. L. Johnson, College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L R Hulse, University of Arkansas, Fayetteville, Ark
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
California, Univ. of..Feb. 9, '12	J. F. Pollard.	B. D. Dexter, 1725 Euclid Ave., Berkeley Cal.
Case School, Cleveland Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio
Cincinnati, Univ. of..Apr. 10, '08	W. H. Jefferson.	Oscar Plueddemann, University of Cincinnati, Cincinnati, O.
Colorado State Agricultural College.......Feb. 11, '10	D. E Byerley.	A A Catiin, 626 So Meldrum St, Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	F. A. Fish.	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	L. J. Kieser.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	B. F. Hillebrandt.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of...............Oct. 14, '10	W. H. Jaegle.	J H. Gaiser, 341 Harrison Ave, Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa.
Lewis Institute.......Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	Benjamin Haskell	John E. Ash, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, 432 Thompson St., Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	J. Glen Luther.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	
Ohio Northern Univ. Feb. 9, '12		
Ohio State Univ......Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.....Oct. 13, '11	W. E. Dolde.	H. P. Cook, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.
Oregon State Agr. Col. Mar. 24, '08	H. Belknap.	W. R. Varner, Oregon St Agric College, Corvallis, Ore
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02		
Purdue Univ........Jan. 26, '03	C. F. Harding.	A. L. Topping, Purdue University, Lafayette, Ind.
Rensselaer Poly. Inst. Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Rose Polytechnic Inst. Nov. 10, '11	Jerry H. Service, Jr.	David W. Jones, 911 North 8th Street, Terre Haute, Ind.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ........Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N Y.
Texas, Univ. of.......Feb. 14, '08	J. A. Correll	N. H. Brown, University of Texas, Austin, Tex.
Throop Poly. Inst....Oct. 14, '10	Frank C. Miller.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson	O Krupp, 65 North Bend St, Burlington, Vt.
Virginia, Univ. of..Feb. 9, '12		
Wash., State Coll. of..Dec. 13, '07	M K Akers	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Irwin L Cheney	P S Stevens, Washington University, St Louis, Mo
Worcester Poly. Inst. Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly Inst., Worcester, Mass.
Yale University......Oct. 13, '11	B. C. Beck.	J. H. Shallenberger, 166 Vanderbilt-Scientific, New Haven, Conn.

Total, 42.

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of
THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol XXXI **April, 1912** No. 4

Next Regular Meeting of the A.I.E.E., New York, April 5, 1912

The two hundred and seventieth meeting of the A. I. E. E. will be held in the Auditorium of the Engineers Building, 33 West 39th Street, New York, on Friday, April 5, 1912, at 8:15 p.m. The meeting will be under the auspices of the Railway Committee, and Mr. Samuel Insull, president of the Commonwealth Edison Company, of Chicago, will present a paper on " The Relation of Central Station Generation to Railway Electrification."

The vital importance of a discussion of this subject, in view of the early probability of great advances in the equipment of trunk lines for electric operation, hardly needs to be emphasized. The bearing, from the standpoints of both reliability and economy, of unified supplies, can be demonstrated by no abler authority than Mr. Insull, whose development and management of the Chicago stations has been, to an exceptional degree, unique, daring and successful.

Owing to unavoidable delay in preparation, the paper will not be printed in advance of the meeting, but ample opportunity for discussion will be afforded later.

The meeting will be called to order promptly, and will adjourn at ten o'clock, after which the usual smoker will be held in the Institute offices on the tenth floor, where light refreshments will be served.

Pacific Coast Meeting at Portland

As previously announced, the Pacific Coast meeting of the Institute will take place at Portland, Oregon, April 16-20, 1912. The committee as appointed by President Dunn, which will have charge of the details of the meeting, is as follows:

Messrs. F. D. Weber, Chairman,	Portland,	Ore.
H. R. Wakeman	"	"
P. Lebenbaum,	"	"
L. B. Cramer,	"	"
C. L. Wernicke,	"	"
W. D. Scott,	"	"
S. G. McMeen	"	"
W. S. Turner,	"	"
O. B. Coldwell,	"	"

S. B. Charters, San Francisco, Cal.
A. A. Miller, Seattle, Wash.
F. D. Nims, Vancouver, B. C.
O. H. Ensign, Los Angeles, Cal.
J. B. Fisken, Spokane, Wash.

PAPERS

The following papers are included in the technical program:

Operation of Two Alternating-Current Stations through Parallel Circuits and the Distribution of Load and Wattless Current Between Them, by J. W. Welsh.

Air Gap Flux Distribution in Direct Current Machines, by Charles R. Moore.

Principles to be Considered in Selecting a Water-Wheel Unit, by O. B. Coldwell.

Irrigation in the Spokane Valley, by L. J. Corbett.

An Underground System and a Few Developments, by S. B. Clark.

Alternating-Current Systems of Underground Distribution, by S. J. Lisberger and C. J. Wilson.

Automatic Private Branch Exchange Development in San Francisco, by Gerald Deakin.

Application of Automatic Selecting Devices to Telephone Multiple Switchboards, by Alfred H. Dyson.

Plant Efficiency, by J. D. Ross.

Practical Joint Pole Construction, by J. E. Macdonald.

Design of Telephone Pole Lines for Conditions West of the Rocky Mountains, by A. H. Griswold.

Arc vs. Tungsten Street Lighting in Small Towns, by C. E. Stephens.

Mechanical Results of the Use of Suspension Insulators, by V. H. Greisser.

Long-Distance Telephone Transmission on the Pacific Coast, by C. A. Turner.

The first six papers listed above have been published in the March and April PROCEEDINGS. Copies of the other papers to be presented will be distributed at the meeting.

The local committee is making arrangements for the entertainment of the visiting members, which include a number of trips to various points of interest in and around Portland. Special trips for the ladies accompanying visiting members are also being arranged. The complete schedule of these trips will be given in the program which will be issued shortly by the local committee.

The headquarters of the Pacific Coast meeting will be in the Hotel Multnomah, the rates for which have been published in the March PROCEEDINGS. Applications for reservations should be addressed to Mr. H. C. Bowers, manager Multnomah Hotel Company.

TRANSPORTATION

Members attending the Portland Convention may take advantage of reduced rates on the certificate plan, which have been granted by the railroads mentioned below. Under this plan the round trip fare will be one and one-third times first-class single fare.

Members should purchase a ticket to Portland at full fare rate and at the time of purchasing ticket should obtain a receipt certificate showing that full fare rate has been paid. This certificate should be signed by the purchaser and handed to the Secretary of the meeting for his signature. The Secretary will present these certificates to the joint agent of the railroad companies, who will stamp them providing there are fifty or more certificates received. These certificates should be presented to the ticket agent when purchasing return tickets, and will permit the agent to issue return tickets, *via* going route only, at one-third regular one-way fare.

Certificates will be issued only for tickets purchased during the three days prior to the opening of the meeting, not including Sunday, and during the first three days of the meeting. The following railroads have named the certificate plan:

Southern Pacific, for points in Oregon, including the Corvallis and Eastern Railroad, and the Pacific Railway and Navigation Company and also covering points in California.

The Spokane & Inland Empire R.R., from points in Washington.

The Northern Pacific Railroad Co., from all points in Idaho, Washington, and Oregon, on the Northern Pacific Railway, including the Camas Prairie Railroad.

The Oregon-Washington Railroad and Navigation Co., all points on this line.

Canadian Pacific Railroad, from all points in Idaho, Oregon, and Washington.

The Spokane, Portland, and Seattle Railroad, from all points on this line, including the Oregon Trunk Railway, and the Oregon Electric Railway.

Great Northern, from all stations in Oregon, Washington, and Idaho.

A complete program of the meeting containing further details as to transportation, etc., will be issued by the local committee.

Pittsburgh Meeting, April 25-27, 1912

The details of the Pittsburgh meeting of the Institute, April 25-27, 1912, are now practically completed.

This meeting will be held under the auspices of the Pittsburgh Section and the Industrial Power Committee, and the Association of Iron and Steel Electrical Engineers will also join in this meeting. The Industrial Power Committee has supplied the technical program which consists of the following papers:

The Electrical Construction of a Large Mine Hoist, By H. W. Cheney.

The Use of Alternating Current in Unloading Coal, By W. N. Ryerson and J. B. Crane.

Electrification of a Reversing Mill of the Algoma Steel Company, By Bradley T. McCormick.

Self-Starting Synchronous Motors, By C. J. Fechheimer.

Does it Pay the Average Coal Mine to Purchase Central Station Power? by G. Bright.

Direct Current and Alternating Current Mill Motors for Auxiliary Drives, by Brent Wiley.

Advantages of Automatic Control in Steel Mill Operation, by Stewart C. Coey.

Operation of a large Electrically driven Reversing Mill, by W. Sykes.

The Electrical Braking of Induction Motors, by H. C. Specht.

Motor-Driven Reversing Mill at American Sheet and Tin Plate Co., by J. E. Smith.

Application of Motors to Large Valves and the Method of Controlling Them, by H. M. Gassman.

The first four of the above papers will be found in the March and April issues of the PROCEEDINGS. The balance of the papers will be distributed in pamphlet form at the meeting.

The officers of the Pittsburgh section have selected the Fort Pitt Hotel as the headquarters for the meeting and the technical sessions will be held in the English room of that hotel. All reservations for hotel accommodations should be made direct with the management of the Fort Pitt Hotel. The rates are as follows:

FOR ONE PERSON

Room	$1.50	$ 2.00
Room with shower bath	2.00	$ 4.00
Room with bath	2.50	5.00

FOR TWO PERSONS

Room	$2.50	$ 3.00
Room with shower bath	3.00	5.00
Room with bath	3.50	7.00

No special rates of transportation have been arranged for this meeting.

A number of trips to industrial plants in and around Pittsburgh have been arranged which will include visits to steel works, gas works, the Westinghouse Electric & Manufacturing Co., and possibly coal mines. Some trips of interest have also been arranged in and around Pittsburgh for the ladies attending the meeting. In order to have more time to visit the industrial plants, it is proposed to hold evening sessions on Thursday and Friday, April 25th and 26th. A complete program of the meeting has been arranged by the Pittsburgh Section, and will be printed for distribution at the meeting.

Institute Meeting at Schenectady

The technical program of the Schenectady meeting which is to be held in that city May 17, 1912, under the auspices of the Schenectady Section, consists of the following papers:

The Induction Generator, H. M. Hobart.

Electrical Characteristics of Suspension Insulators, F. W. Peek, Jr.

Propagation of Impulses on a Transmission Line, J. H. Cunningham and C. M. Davis.

Ozone; Its Properties and its Commercial Production, M. W. Franklin.

Protection Against Surges on Electric Railways, E. E. F. Creighton, F. R. Shavor, and R. P. Clark.

Lightning Protection for 2,300-Volt Pole Transformers, E. E. F. Creighton and F. R. Shavor.

Multi-Discharge Recorder for Recording Switching and Lightning, E. E. F. Creighton, H. E. Nichols, and P. E. Hosegood.

Modern Construction of Transmission Lines, R. A. Worcester.

Some Impressions of the Electric Traction Situation in Europe, C. E. Eveleth.

Notes on the Actual Cost of Electrification, J. R. Hewett.

Gas-Electric Cars, E. E. Kimball.

Freight Train Tests on an Electric Interurban Railway, S. T. Dodd.

The Generator in Transmission Work, D. B. Rushmore.

Instantaneous Variation of Candle Power of Lamps as Effected by Dynamo Regulations, H. F. T. Erben.

Among other entertainment features which will be provided by the local Section will be several demonstrations of high-tension line phenomena. More complete details of the program will be included in the May issue of the PROCEEDINGS.

Annual Convention at Boston

The arrangements of the Meetings and Papers Committee for holding the Annual Convention of the Institute in Boston, June 24th to 28th, were confirmed by the Board of Directors at its last meeting, and President Dunn announced the appointment of the following Convention Committee:

Messrs. C. L. Edgar, Chairman; Charles B. Davis, Chairman, Sub-committee on Entertainment; W. H. Blood, Jr., Chairman, Sub-committee on Finances; Louis D. Gibbs, Chairman, Sub-committee on Hotel Arrangements; Frederick P. Valentine, Chairman, Sub-committee on Program.

Harry U. Badeau,
Charles F. Bancroft,
E. E. Boyer,
George M. Bates,
John W. Corning,
Harry E. Clifford,
Walter A. Hall,
William L. Hooper,
Dugald C. Jackson,
Frederick M. Kimball,
Daniel Manson,
Harold Pender,
Herbert S. Potter,
George A. Rodenbaeck,
Frank J. Stone.

An interesting technical program is assured, as a number of papers to be read at the Convention are already in hand. All papers designed for presentation at the Convention must be forwarded to Institute headquarters previous to May 1st in order to insure advance publication in the PROCEEDINGS. Further details will be published in coming issues of the PROCEEDINGS.

Special Boston Convention Session

The Committee on Meetings and Papers has decided to devote one session at the Convention to papers and discussions on "Electrical Measurements."

The intention is to have a number of short papers, the presentation of which, by abstract, must not exceed five minutes. The papers will not necessarily be restricted to a length that could be completely read in five minutes, but the idea is to have them short and to cover some specific point, rather than to have them general in their scope. They will probably relate mostly to descriptions of novel instruments or meters, methods of performing specific tests, etc. Practical requirements which have arisen, and for which no satisfactory apparatus or method has been developed, would furnish a suitable subject. Theoretical presentation is desired only in connection with the explanation of practical applications.

Contributions of short papers are solicited for this session. The following have already agreed to either contribute papers or obtain them from their associates, and arrange to have them presented at the session:

J. W. Cowles, Alexander Maxwell, C. E. Skinner, W. L. Robb, E. B. Rosa, F. P. Cox, Alexander H. Sharpe, G. A. Sawin, T. H. Amrine, E. F. Northrup,

F. V. Magalhaes, S. G. Rhodes, F. M. Farmer, A. McK. Gifford, A. F. Ganz, Evan J. Edwards.

Copies of papers for this session should be mailed before May 1, 1912, to L. T. Robinson, care of General Electric Company, Schenectady, N. Y.

Future Section Meetings

TORONTO

The Toronto Section will hold its next regular meeting on Friday evening, April 12, at the Engineers' Club, Toronto, Ont. Mr. Wills Maclachlan will present a paper on " The Electrical Equipment of the Port Colborne Elevator."

Resumé of Proceedings of Directors' Meeting of the American Institute of Electrical Engineers, Friday, March 8, 1912

The following members of the Board were present: President Gano Dunn, New York; Past President Dugald C. Jackson, Boston, Mass; Vice-Presidents Percy H. Thomas and W. G. Carlton, New York; David B. Rushmore and Charles W. Stone, Schenectady, N. Y.; Managers A. W. Berresford, Milwaukee, Wis.; William S. Murray, New Haven, Conn.; Henry H. Norris, Ithaca, N. Y.; Severn D. Sprong, Brooklyn, N. Y.; H. H. Barnes, Jr., and Walter S. Rugg, New York; F. S.Hunting, Fort Wayne, Ind.; Farley Osgood, Newark, N. J.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York. Monthly bills of $8,559.42 were approved for payment.

The arrangements of the Meetings and Papers Committee for holding the annual connvention of the Institute in Boston, from June 24th to June 28th, inclusive, were confirmed and the President announced the following Convention Committee: Mr. C. L. Edgar, chairman; Professor Dugald C. Jackson, Prof. William L. Hooper, Prof. Harry E. Clifford. Prof. Harold Pender, W. H. Blood, Jr., Charles B. Davis, Frederic P. Valentine, Louis D. Gibbs, Herbert S. Potter, Daniel E. Manson, George M. Bates, Frank J. Stone, John W. Corning, Charles F. Bancroft, George A. Rodenbaeck, Walter A. Hall, Frederick M. Kimball, Harry U. Badeau and E. E. Boyer, of which, on the nomination of Mr. Edgar, Mr. Davis was appointed chairman of the sub-committee on entertainment, Mr. Blood chairman of the sub-committee on finances, Mr. Gibbs chairman of the sub-committee on hotel arrangements, and Mr. Valentine chairman of the sub-committee on program and to confer with the Meetings and Papers Committee of the Institute. Authority was given the President to add to these committees.

The President announced the appointment of the Pacific Coast Convention Committee as follows: Messrs. F. D. Weber, chairman, H. R. Wakeman, P. Lebenbaum, L. B. Cramer, C. L. Wernicke, W. D. Scott, S. G. McMeen, W. S. Turner, O. B. Coldwell, all of Portland, Oregon; S. B. Charters. Stanford University, Cal.; A. A. Miller, Seattle, Wash.; F. D. Nims, Vancouver, B. C.; O. H. Ensign, Los Angeles, Cal., and J. B. Fisken, Spokane, Wash.

There were transferred to full membership Messrs. Edward H. Everit, Frederick W. Ells, L. A. Osborne, Nicholas Stahl, Nathan Hayward, George L. Hoxie, Clayton H. Sharp, Alexander C. Humphreys, Carl J. Fechheimer.

One hundred and eighteen associates were elected and eighty-four students enrolled.

On the unanimous recommendation of the Committee on Code of Principles of Professional Conduct, consisting of Prof. George F. Sever, chairman, Mr. Harold W. Buck, Col. Samuel Reber, Dr. Charles P. Steinmetz, Mr. Henry G. Stott and Dr. Schuyler Skaats Wheeler, supported by the recommendation of Messrs. Louis Bell, John J. Carty, Francis B. Crocker, Dugald C. Jackson, A. E. Kennelly, John W. Lieb, Jr., Henry H. Norris, Ralph W. Pope, Harris J. Ryan. Charles F. Scott, Samuel Sheldon, William Stanley, Elihu Thomson, and W. D. Weaver, representing fourteen of the jury of eighteen leading members of the Institute to whom the Code was referred for approval before it was presented to the Board of Directors, the Board confirmed the unanimous tentative approval given at its meeting a month ago, and adopted by the vote of all present except one, the final draft of the Code as presented in the Committee's report, thereby completing the work initiated by Past President Wheeler in his address on Engineering Honor before the Annual Convention of 1906. The full text of the Code, which is brief, appears elsewhere in this issue.

The thanks of the Board were voted to the Committee, the continuation of which as one of the permanent committees of the Institute to revise and add to the Code from time to time on receipt of criticisms and suggestions from members, was authorized, thus putting the Code, in its relation to the membership, in the same position as the Standardization Rules.

The President announced that the officers of the Committee on Organization of the International Electrical Congress of San Francisco, 1915, would be:

Dr. Charles P. Steinmetz, President;

Dr. A. E. Kennelly, Vice-President in charge of Program;

Mr. C. O. Mailloux, Vice-President in charge of International Relations;

Mr. W. D. Weaver, Vice-President in charge of Organization;

Mr. Henry A. Lardner, Vice-President in charge of Pacific Coast Relations;

Dr. E. B. Rosa, of the United States Bureau of Standards, Secretary:

Mr. Preston S. Millar, of the Electrical Testing Laboratories, Treasurer and Business Manager.

The body of the Committee will be announced later, as well as the advisory and honorary members, who are to be chosen by the committee itself with the cooperation of the International Electrotechnical Commission and of the engineering, scientific and technical bodies of the United States, Canada and Mexico.

The memorial of the convention of delegates of American engineering societies, held in San Francisco on January 15th to formulate plans for holding an International Engineering Congress at San Francisco, having been sent to all the members of the Board, which at its meeting in January voted to support such a general engineering congress, was referred to the Committee on International Electrical Congress for recommendation.

The Power Transmission Committee of the National Electric Light Association, through Mr. John R. McKee, having brought to the attention of the Institute the draft of a water-power bill designed to improve the existing conditions holding back the economical development of water powers, the Public Policy Committee of the Institute gave as careful consideration to this bill as the short time between its receipt and the meeting of the Board of Directors permitted. Chairman Carty of the Public Policy Committee, on hearing from a number of the members of the Committee, recommended that the Institute abstain from either approving or disapproving the bill until further time for its consideration could be had. The Board of Directors, to each member of which a copy of the bill had been sent in advance of the meeting, voted to approve this recommendation, and referred the measure back to the Public Policy Committee with the request that after further consideration of the bill by the Public Policy Committee, and the obtaining of further information regarding it, a further report to the Directors' meeting of next month be made. The desire of the Institute to coöperate in every way with its sister society, the National Electric Light Association, was most cordially expressed.

On account of the large number of members of the Institute resident in India, the Board voted to look out for their interests by the establishment of a local Honorary Secretary at Mysore, and, on recommendation of the President, Mr. Clare F. Beames, formerly local Honorary Secretary of the Institute at Mexico, received the appointment.

There having been received from Mr. Paul Janet, Director of Laboratoire Centrale and of the Ecole Superieure d'Electricite, of Paris, a communication to the President of the Institute, inviting subscriptions to a memorial fund in honor of the memory of the late distinguished electrical engineer, J. Joubert, the Directors passed a resolution expressing their sympathy with the movement and their appreciation of the opportunity thus given them to do honor to the name of the eminent French scientist, and authorized the appointment of a committee to receive subscriptions. On this committee were appointed Mr. C. O. Mailloux, chairman; Mr. Charles E. Scribner, Dr. Carl Hering and Prof. Comfort A. Adams.

The report of the Tellers canvassing the nominating votes for officers for the ensuing year showed that about fifteen per cent. of the membership of the Institute had cast nominating ballots. Guided, although not controlled, by these ballots, in view of the provision of the Constitution constituting the Board of Directors a nominating committee with discretion, the Directors, having in mind territorial representation and the desirability of officers as far as possible representative of all the elements in the Institute, chose the following candidates to be submitted as Directors' nominees to the vote of the memship, recognizing that the Directors' ticket is intended to be only an assistance in indicating candidates to the membership and that it does not in any way prevent the election of other candidates, should they be preferred by the membership: For President, Mr. Ralph D. Mershon, of New York; for Vice-Presidents, Mr. William S. Murray, of New Haven, Mr. Arthur W. Berresford, of Milwaukee, Mr. S. D. Sprong, of Brooklyn; for Managers, Prof. Comfort A. Adams, of Cambridge, Mr. William B. Jackson, of Chicago, Mr. J. Franklin Stevens, of Philadelphia, Mr. William McClellan, of New York; for Treasurer, Mr. George A. Hamilton, of Elizabeth; for Secretary, Mr. F. L. Hutchinson, of New York.

In the case of the Secretary, it is interesting to note that the membership in their nominating votes united in endorsing Mr. F. L. Hutchinson, whom the Board had appointed to be the successor of Mr. Ralph W. Pope.

The official ballots indicating the Director's nominees will be sent out to the membership on the first of April.

There will be sent out on the twenty-first of March ballots covering the constitutional amendments providing for an additional grade of membership, by which the present two grades of Associate and Member will be rearranged into three grades,—a new one called "Fellow" being added at the top, the grade of Member remaining as it is with somewhat reduced qualification for admission, and the grade of Associate being unchanged. The dues of the highest grade, which it is expected will include, as it does at present, approximately ten per cent. of the membership of the Institute, and for which an experience of ten years is required, are to be $5.00 higher than the dues for the present grade of Member; the dues for the grade of Member and the dues for the grade of Associate remain unchanged.

The St. Louis Section some months ago on account of a deep interest in the efficiency of the United States patent system, passed resolutions petitioning the President of the United States to investigate and remedy certain defects. The Board of Directors felt that the policy of the Institute in a national matter should be expressed by the whole Institute as represented by the Board and, after correspondence with the St. Louis section and on recommendation of the Public Policy Committee, it authorized the appointment of a special and representative Patent Committee which should take up the questions raised by the St. Louis Section, investigate them carefully and make such report and recommendations as could be adopted by the Board and used to further the object in view. In the selection of this committee, great care has been taken to see that it was representative of inventors, engineers, manufacturers and lawyers, and composed from among the leaders of these elements in the Institute, and that it was as nearly non-partisan in any direction as could be made. The names of the following members who have accepted the responsibility of service on this important committee were announced by the President. They are: Chairman, Dugald C. Jackson, consulting engineer and patent expert, past-president of the Institute; A. W. Berresford, manufacturer and patent expert; J. H. Bruninga, patent lawyer, nominated by the St. Louis Section; James Burke, electrical engineer, inventor and manufacturer; Frederick P. Fish, leading member of the patent bar; Kempster B. Miller, consulting electrical engineer and patent expert; M. I. Pupin, physicist, inventor and electrical engineer, and C. E. Scribner, electrical engineer, inventor and manufacturer. This committee is expected to confer with the committees of other organizations that have been appointed for the same purpose.

The President announced that he was intending to go to Portland, Oregon, to preside over the Pacific Coast Convention of the Institute to be held there from April 16th to 20th, and that he hoped to visit the St. Louis, Los Angeles and San Francisco Sections on the way out, and the joint meeting of the Institute and the Association of Iron and Steel Electrical Engineers in Pittsburgh, under the auspices of the Industrial Power Committee and the Pittsburgh Section, on April 25-27, on his return.

Engineering Reports Desired by the New York Public Library

The New York Public Library wishes to supplement its files of technical periodicals and similar collections of source material with the monographs and reports on various engineering enterprises that appear in print from time to time. Publications of this nature appearing in the regular book trade are bought by the Library and such as appear in the periodical literature of engineering are indexed, but the separate pamphlet reports that represent so large a part of the literature of this kind can be obtained only through the courtesy and thoughtfulness of the engineers making such reports.

The Director of the Library has asked that this notice be brought to the attention of the members of the Institute, with a request that they send to the Library copies of reports on engineering enterprises made by them. Material of this kind that is forwarded to the Library will be catalogued and preserved, and will be of lasting benefit to the donors and to students working along the same lines.

Addresses Wanted

Name	Former address
H. H. Bales,	Ashcroft, B. C.
H. H. Hess,	Hellertown, Pa.
Wm. A. Hirt,	Evanston, Ill.
J. R. Klippelt,	Kirksville, Mo.
F. C. Newell, Jr.,	38 Vesey St., New York, N. Y.
F. W. Randall,	Ellenville, N. Y.
J. W. Rutherford,	283 Summit Ave., Jersey City, N. J.
Peter V. Schupp,	Minneapolis, Minn.
James P. Starrett,	Lynn, Mass.
C. A. Tozer,	Spencerport, N. Y.
F. W. Up de Graff,	Pachuca, Hidalgo, Mexico.
J. S. VanBylevelt,	Dresden, Germany.
T. Philip Walker,	36 Burton Ave., Montreal, Que.
G. M. Willis,	25 E. Walton Place, Chicago, Ill.

Members or Associates who can give information that may assist in obtaining any of these addresses are requested to communicate with the Secretary of the Institute.

THE FORUM

Dedicated to the Discussion of Institute Affairs

PROPOSED AMENDMENT FOR ADDITIONAL GRADE OF MEMBERSHIP

To the members of the A. I. E. E.

In connection with the ballots that have just been sent to the membership for voting on the constitutional amendments proposing to add an additional degree of membership to our present schedule, I should like to call the attention of the members to some of the difficulties that the Committee on Additional Grade of Membership found in its work.

While there was, when the committee took up its work, a strong sentiment that an additional grade should be added, there was the widest divergence of views as to the exact plan to be followed. It was necessary, however, for the committee to arrive at some definite conclusion, and therefore, starting with the work of the last committee, a concrete form of amendment was prepared and submitted to a large number of persons, who had given special thought to this phase of Institute affairs. As a result, substantially the present amendments were arrived at, which, while not fitting in detail exactly the ideas of any one person, follow closely the average consensus of opinion.

It will not be necessary, in view of the full explanations already given of the reason for arriving at the present form, for me to discuss the amendments in detail. I should like to say, however, in regard to the matter of dues for the three grades, it appeared to all to be desirable with three grades instead of two to raise the dues of the highest grade somewhat, to be proportionate to the high distinction it was hoped would be accorded to Fellows. It was not feasible to reduce the dues of the Associate class, since they greatly outnumber the Fellows, and the expenses of the Institute are rapidly mounting, especially with the growth of the Sections in number and importance. Since the Members are intermediate in standing, intermediate dues are appropriate, and the amount of the dues chosen is a natural mean. If any prospective Members should think $15.00 to be too high a rate I hope they will consider that the committee and the Board of Directors have done the best they could to meet the approval of the majority of the membership. After all, the amount of dues is, at least within the limits we have set, of much more importance to the Institute as a whole than to the individual members, for with any added resources, its activities can be much more than proportionately increased, and its opportunity to work for the advantage of our profession greatly strengthened.

The committee expects that the new name of "Fellow" chosen will sound strange at first to many of our members, but none of the other names suggested to the committee was nearly as appropriate. The use of the term "Associate Member" was proposed, but the probability of great confusion not only on the part of the public, but our own members, that would be certain to follow the schedule of Associate, Associate Member and Member, was too great to warrant its adoption. As a matter of fact, it appeared to the committee after their study of the situation, that the term "Fellow" is particularly fitting and satisfactory for our highest grade of membership.

Referring to the amendments as a whole, I should like to urge that each member consider as of prime importance the question whether or not an additional grade of membership, along the general lines here proposed, is desirable, and then consider whether any of the particular features here laid down depart sufficiently from his ideal to warrant a negative vote; especially in view of the fact that it is extremely improbable that amendments can or will be drawn to meet his particular objection, in view of the thousands of members involved, and the slowness of the procedure prescribed for Constitutional amendments.

PERCY H. THOMAS.
Chairman Committee on Additional Grade of Membership.
March 15, 1912.

To the members of the A.I.E.E.

Now that the full details of the proposed plan for an additional grade of membership in the American Institute of Electrical Engineers have been approved by the Board of Directors and laid before the Institute, I should like to say a few words on one or two of the features of the proposed plan. I realize, of course, that no plan could be devised which, in all of its details, will meet the exact views of every member of the Institute. The committee preparing the suggested amendments to the Constitution has, however, used its best and most earnest efforts to obtain all of the facts bearing upon the question under consideration and to formulate, guided by these facts, amendments which would, in its judgment, if adopted, be conducive to the best interests of the Institute as a whole and would, at the same time, be fair to the present Members and Associates.

Much time and thought was given to the question of what name should be used to designate the third grade introduced by the proposed changes. Terms such as " Junior Member" and " Associate Member " were carefully considered by the committee, but after receiving the testimony of those engaged in carrying on the routine of the Institute office work and hearing from them of the difficulties which were experienced even at the present time with the present arrangement where the term "Member " is used to designate one grade while the term " member " is used to designate all of those having membership in the Institute, it was felt that it would be exceedingly desirable, in connection with introducing a third name, to do so in such a manner as would not make further complications of the kind referred to. This could best be done by using a term which contained neither the word " associate " nor the word " member." After much study on this point the committee found, all things considered, that the term " Fellow " would be most satisfactory. While its use is, perhaps, a departure from the nomenclature heretofore used by American engineering societies, it is believed by the committee that our use of it in the way proposed would be accurate, justified by the circumstances, and likely to be followed by other engineering societies.

Careful thought was given to the question of the dues which should be paid by the proposed grades. While it is quite true that in many cases those occupying the highest grade of membership in the Institute, whatever it may be called, do not derive from the Institute more in the way of publications or other direct advantages than do those occupying the lowest grade, I think that we should consider this matter from the point of view of what we, as engineers, owe to the Institute. We have a responsibility towards our profession and toward the Institute, which is the official body representing it, and we should all of us be ready to discharge these responsibilities in every way possible. In order that the Institute may perform its functions properly it is necessary that funds should at all times be available which will permit of its carrying on its work in a satisfactory manner. It is not desirable at any time that the Institute should be forced to defer or abandon lines of activity which are otherwise desirable, because the necessary expenditures are beyond its means. Those who constitute the highest grade of membership in the Institute are, by age, experience and professional attainment, in a better position to make larger contributions to the Institute funds than are the younger and less experienced members. Their responsibilities to the profession are greater and it has seemed to me that the dues as fixed by the proposed amendments satisfactorily express in a financial way these increased responsibilities and are fair to all concerned, and that even with the dues of the highest grade of membership at $20, such dues would be no greater burden on those paying them than would the dues of $10 upon those making up the grade of Associates.

BANCROFT GHERARDI,
March 23, 1912.

The following letter addressed by Mr. P. M. Lincoln, chairman of the Sections Committee, to the members of his committee, gives some pertinent facts and figures in regard to the present and proposed dues for the different grades of membership of the A.I.E.E., and compares these dues with those of two of our sister societies. His letter is reproduced here for the benefit of the membership at large.

To the members of the Sections Committee.

Gentlemen: Your Chairman has received, through various sources, a number of objections, which seem to appeal to the membership with more or less force, against the proposed new grade of membership. Objections have been advanced against this amendment upon many grounds: some object to the modification of dues; some object to the name "Fellow"; some object to the requirements for admission to the various grades; some object to the method of determining the fitness of candidates for the various grades—and some just object.

It is only too evident to one who has studied this question that it is impossible to formulate any set of amendments on this question which will satisfy every one concerned. "Many men, many minds," is an adage that applies to this amendment with unusual force. One man objects to this item, a second to that, and a third to still another; we can therefore readily see that the final passage of any amendment covering a third grade of membership is very difficult, if not impossible, unless each member is willing to accept some feature therein that may seem to him capable of improvement—unless, in other words, we are willing to accept a compromise measure.

During the committee's deliberations resulting in the draft now presented to the membership, almost every conceivable alternative was considered. Any new feature in this draft did not "just happen," but was adopted only after the fullest consideration, and then only because it seemed the best compromise among the many divergent minds of the committee.

Although, as indicated above, the proposed amendments have been criticised on many grounds, the new schedule of dues seems to have drawn more fire than any other one item. This matter came up for nearly as much discussion in the committee as any other and the committee considers that there is excellent reason for the new schedule. Perhaps one of the best guides in this matter of dues is to see what our sister societies are doing in this respect. To this end, I have had the following table prepared, showing the complete schedule of dues and entrance fees and the number of members of the various grades in the American Society of Civil Engineers and the American Society of Mechanical Engineers.

One pertinent fact shown by these tables is that the Civil Engineers have dues for certain classes of their membership that are higher than those proposed for the Electricals. Moreover, there are 1,152 Civils out of a total of 6,334—over 18 per cent.—that are paying these maximum dues.

However, it is not perhaps fair to compare these societies on the basis of their maximum dues. The financial burden on the average member is a more correct index of comparison. To secure such an index, we may divide the total income by the total number of mem-

AMERICAN SOCIETY OF CIVIL ENGINEERS

	No.	Annual Dues	Income	Entrance fee
Members—Resident*	617	$25	$15,425	$30
" Non-Resident	2313	15	34,695	
Assoc. Mem. Res.*	535	25	13,375	25
" " Non.-Res.	1889	15	28,335	
Associates-Res.*	170	15	2,550	20
" Non.-Res.	6	10	60	
Juniors-Resident*	78	15	1,170	
" Non.-Res.	726	10	7,260	10
	6334		$102,870	

Average annual dues per member—$16.23
Average entrance fee per member—$25.25

*Living within 50 miles of New York.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

	No.	Annual dues	Income	Entrance fee
Members	2774	$15	$41,610	$25
Associates	374	15	5,610	25
Juniors	951	10	9,510	15
Totals	4099		$56,730	

Average annual dues per member..... $13.83
Average entrance fee per member..... $22.65

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

(Present conditions—Jan. 1, 1912.)

	No.	Annual dues	Income	Entrance fee
Members	705	$15	$10,575	$15
Associates	6450	10	64,500	5
	7155		$75,075	

Average dues per member......... $10.50
Average entrance fee per member... 6.00

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

(Under proposed dues)

	No.	Annual Dues	Income	Entrance fee
Fellows	705	$20	$14,100	$20
Members	3225	15	48,375	15
Associates	3225	10	32,250	5
Totals	7155		$94,725	

Average annual dues per member....$13.23
Average entrance fee per member*...$12.06

* This item is inserted for comparison only, and indicates what the average entrance fee would be, provided the proposed dues were in force and the membership had paid entrance and transfer fees accordingly. The amendment provides, however, that present Associates and Members may be transferred without the payment of a transfer fee, hence this item does not apply to the present membership.

SUMMARY

	Average dues	Per cent	Average Entrance fee	Per cent
Civil Engineers	$16.23	155	$25.25	421
Mechanical Engineers	13.83	131	22.65	377
Electrical Engineers (present)	10.50	100	6.00	100
Electrical Engineers (Prob. future)	13.23	126	12.06	201

bers of all grades—the result so obtained being the average financial burden. The results of such an operation are given herewith, both in respect to the annual dues and the entrance fees. The same data are included for our own Institute. One table of data covers the present conditions in our Institute and another is a liberal estimate made up for an assumed future condition, which seems to arrive at an average financial burden certainly as large as present indications would justify. The assumptions for this future condition are that there will be as many Fellows as there are now Members, and that the remainder will be equally divided between the new grades of Member and Associate.

This summary tells a story that I do not believe has been appreciated by our membership. It shows that the financial burden on the average member of our society has been much less than that on the average member of our two sister societies, and that under the proposed modifications the financial burden for the Electricals will still be less than in our sister societies. I, for one, believe that the electrical engineer is justified in paying as much for the service he receives from his society as the civil or mechanical engineer pays for his. The fact that we are getting more for our money should be ground for congratulating ourselves rather than for objections to the proposed modifications. A point that should be borne in mind in this connection is that the dues of no existing member are increased. He must voluntarily change his grade before any change in dues takes place.

Another point to which attention may properly be called is the fact that the Civil Engineers charge considerably more for resident membership than for non-resident—meaning by resident members those living within 50 miles of New York. The only justification for this increase is the personal contact with the Society that is enjoyed by resident members.

The Electrical Engineers, as you all know, have followed a different policy in this respect. They have endeavored to make personal contact with the Institute available to each member by the policy of establishing sections, so that practically every member of the Institute becomes a member of some section, and thereby receives the personal contact whether he lives 50 miles from New York or 5,000 miles. Thus the element of personal contact which the Civil Engineers limit to those in the vicinity of New York, and deem worth $10 extra in annual dues, is extended to a large majority of members of our society, and without additional cost. If additional funds accrue to our Institute from the operation of the new schedule of dues, these funds will be used to extend the usefulness of the Institute, particularly in the direction of more sections or increased activities in the existing sections.

I have gone thus somewhat fully into the question of dues, since this question seems to have met with more objection than any other one point, and because it is a matter that seems to be less understood than any other.

Another objection that some members have made is to the name Fellow. President Dunn has presented the reasons for its selection quite thoroughly in the February issue of the PROCEEDINGS. At best, the question is simply one of name only, and there seem to be many arguments in favor of the name of Fellow for the highest grade and the existing names for the other two grades, as against some other method of naming the three proposed grades. It is true that this name is a new one among the four great national engineering societies of America, but I see no reason why our Institute should not undertake to make a precedent in this regard.

There are many other points that might be taken up in this letter, but it has run into sufficient length already. Personally, there are some things in the proposed amendments that I should like to see changed, but I am perfectly willing to sink my personal preferences on something that is not absolutely essential, with the feeling that what we have before us now is about the best compromise that can be effected.

I should like to see this matter receive the fullest possible discussion in each section, and the advisibility of accepting or rejecting the amendments brought to final vote. I should be pleased to receive the result of such a vote for transmission to the other sections, provided, of course, that the section taking a given action has no objection to making known that action to other sections.

Respectfully yours,
P. M. LINCOLN, *Chairman.*
March 19, 1912.

To the members of the A. I. E. E.

The adoption of the Additional Grade of Membership amendments would strengthen the Institute by accomplishing at once two things long desired and increasingly demanded as the Institute grows—the establishment of a grade of membership higher than that of Member, and the moderate modification of the grade of Member so that instead of excluding a large proportion of the professional element in the Institute, it would include it.

By reclassifying the grades, on which, in response to the demands of Sections and the membership generally, committees have been at work for four years, certain dangerous centrifugal tendencies will be counteracted and the Institute's solidarity increased. The growth all around the Institute, and largely at its expense, of special societies of one form or another related to electrical engineering, the possibility of the formation of a separate society of consulting engineers, not to mention several other electrotechnical societies that have already been formed, requires that the Institute do every thing in its power to enable its members to find within it what they need to give the freest opportunities for their legitimate professional ambitions and interests. In this direction the present amendments take an important constructive step.

It is recognized that they do not embody all the features many members desire. This is impossible where all members must be considered; but they do represent several years' study of the Institute's needs, the unanimous views of the committee reporting them and the unanimous views of the Board of Directors recommending them.

The highest grade is called " Fellow " in accordance with what is regarded as ample precedent to warrant the term. The quality of experience is approximately the same as for the present Members, only it must cover ten years where it now covers five. The dues are $20.00, which is regarded as in keeping with the dignity and distinction of the grade, within the ability to pay of a person who has been a successful electrical engineer for ten years, and in approximate conformity to the dues of certain other leading societies.

The upper of the two grades into which it is proposed the present Associates shall be divided preserves a high standard of professional qualification. It requires five years' practise and ability to design and take charge, under general direction, of important electrical engineering work. The standard of this grade compares favorably with the grade of Member in a number of other important societies, and because it is expected that it will include by far the largest numbers of the professional element in the Institute, it is called "Member." The dues are not changed. They could have been lowered to equal the dues of Associates, but this would have detracted from the dignity of the grade and would have put the professional group of " Members " in the position of contributing no more to the advancement of their profession than Associates, who, under the new amendments, would be the Institute's general or non-professional element.

The grade of Associate is not changed.

Concerning the transfer of present members to the new grades, attention is directed to the special section of the amendments affecting all persons who are Members or Associates at the time the amendments are passed. This section gives them the right, if exercised within a year, to be transferred without payment of fees, on reference to five or four Members, respectively.

While the dues for Members and Associates are not increased, the fact that through the provisions of the special section in force for the first year, approximately all of the present Members would probably become Fellows, and that a large number of the Associates would probably become Members, means an increase in the Institute's income. This increase is not the object of the amendments, but is incidental.

The schedule of dues, after most extended discussion, has been put at figures that comport with the relative dignity of the grades and with the dues that members in other societies contribute. If membership in the Institute is looked at in the light of a subscription for the TRANSACTIONS, all grades should contribute alike; but for years, in engineering societies generally, and in the Institute, dues have not been regarded as payments for value received, but as opportunity to contribute to the advancement of the profession. They have been adjusted on the basis of the debt a man owes to his profession and have been fixed in proportion to his professional standing and corresponding presumptive ability to contribute. Whatever increase there may be in its income would enable the Institute to strengthen itself by doing more for the building up of its Sections, and in the numerous ways that adequate resources make possible, would enable it to increase the importance and the prestige of the profession of electrical engineering in the United States.

Respectfully submitted,

BOARD OF DIRECTORS.
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

March 21, 1912.

PROPOSED AMENDMENT TO APPOINT THE SECRETARY

To the members of the A. I. E. E.

We, the undersigned, oppose the amendments concerning the appointment of the Secretary which deprive the membership of the right to elect him or to confirm the selection of the Board—for reasons among which are the following:

FIRST: The proposed amendment was initiated by the Board and not by the membership.

SECOND. The office of Secretary should be as nearly permanent as possible, in order to furnish continuity in the management of the affairs of the Institute.

THIRD: The present system has been very satisfactory during the whole life of the Institute.

FOURTH: The Secretary is looked upon by the membership as a delegate at large—their own special representative.

FIFTH: The proposed amendment decreases the protection to the rights of the membership now so carefully safeguarded.

SIXTH: The Constitution already provides for the suspension of the Secretary by the Board.

In view of the above reasons we object strongly to the amendment. We believe that the centralization of power in the control of Institute affairs would be a thing greatly to be deplored.

The election of the Secretary at present is most elaborately safeguarded for the benefit of the membership, and the proposed changes give no assurance of any compensation for the loss of such benefit.

President Dunn, on page 97 of the March PROCEEDINGS, compares the appointment of the Secretary to business organizations. Why would it not be better for the stockholders in a business corporation to follow our successful administration?

His reference to the practice in other

societies fails to mention that many of them do elect their secretary.

What reasonable excuse has the membership for making any change?

H. A. Hornor.
H. Clyde Snook.

To the members of the A.I.E.E.

There will be presented again this year the proposition of amending the Constitution so as to permit the election of the Secretary of the Institute by the Board of Directors. This amendment was actively discussed when it was proposed before, and it is indicative of a healthy interest in Institute affairs that it has again aroused lively debate. It might at this time be pertinent to review some of the considerations that bear on this question.

The affairs of the American Institute of Electrical Engineers are in the hands of a representative body, which is not of the self-perpetuating kind, but which represents the membership at large—both geographically and objectively as to policies, etc. Experience has shown that this method of direction of Institute affairs has worked efficiently and satisfactorily in the past. From this it follows that the Board is a really representative body, acts in a representative capacity, and justifies the confidence of the membership in the Board's control of Institute affairs.

To provide for an efficient working machine with a continuance of general policy, the Board is made up of a certain number of new members each year, and the retirement of an equal number who have served for a period of years, thus avoiding any extensive changes of personnel at one time. For the same reasons it is desirable that the Secretary be continued in office as, regardless of large capabilities at the start, his value will increase from year to year as he becomes more familiar with the policy of the Institute, its precedents and routine. This implies careful discrimination in the original selection of the Secretary, which in itself requires a personal knowledge of the individuals under consideration for a proper estimate of their fitness. It does not imply, however, a continuance in office if under control of the Board and in case of demonstrated lack of fitness or inefficiency. While the Board may have at present authority to suspend a Secretary, this would be an extreme and very remote action, as there are so many degrees of inefficiency between the best and the low point which would justify suspension. The Board, in the case of an indifferent Secretary, would carry the whole responsibility, although its hands would be tied to remedy a situation that would be very apparent to itself both as to cause and how to correct it, but would naturally hesitate to suspend.

The Institute is a national body with all the advantages and disadvantages that are inherent in a distributed membership. Among the disadvantages is the impossibility of any considerable number of our members getting a sufficient personal knowledge of any individual to exercise proper judgment in the selection for nomination, or election, of a Secretary, when a number of candidates may appear. The objection may be made that this applies equally to the office of President, but this argument is not sound in view of the fact that men who have risen to the point of serious consideration for the office of President are men of national prominence, who have long been active in Institute affairs, and have approached a point in the general knowledge of the membership as a whole where they are known to represent the policies and ambitions of the Institute. For these reasons, the office of President is not comparable with the office of Secretary, and for the additional reason that their places in the activities of the Institute are very dissimilar. The principal function of the Secretary is well described in the words of the Constitution as the executive officer of the Institute under the direction of the President and Board of Directors. His work as executive officer is obviously the carrying into active form the instructions of the Board of Directors.

It is a reasonable assumption that the membership as a whole has confidence in its representatives and the Board of Directors. If this is so, and to them is delegated the very responsible care of Institute affairs in all their varied phases, what serious objection can there be to authorizing the Board of Directors to select the executive officer, who, being elected by the membership, the Constitution makes responsible to the Board? While the Board originated the suggestion to amend the constitution, it was by way of insuring efficiency with power to maintain the same, and with no thought of adding to its prerogatives, as these are already supreme so far as the directing force in Institute affairs is concerned. Some have observed that the present method has worked successfully during the whole life of the Institute, but thought should be given to the fact that in the early days of the Institute conditions permitted the relatively few of the then limited numbers in the profession and industry to have personal knowledge of the individual under consideration, and experience has shown that they did so discriminate in their most fortunate selection of our venerable Secretary, R. W. Pope. Conditions have greatly changed, and it is the endeavor of the Board to so meet them as to insure, if possible, equally fortunate selections whenever the contingency may arise.

As a matter of fact, the Board of Directors is peculiarly in a position to have direct knowledge of the qualifications of the Secretary, and it seems unwise that the Board be charged on the one hand with full responsibility for directing the affairs of the Institute and then on the other deprived of an important means of making sure that its responsibilities are discharged.

S. D. Sprong.

March 22, 1912.

To the members of the A. I. E. E.

The effect of the Secretary amendments is to provide for the election of the Secretary by the Board of Directors instead of by the membership, but not in any way to change the duties which, to safeguard their interests, the members have provided for the Secretary, nor to remove him from under the authority of the Constitution, which enumerates his specific responsibilities.

The Constitution places upon the Board the broadest responsibility and authority for managing the Institute's affairs, and to make sure that there shall be no division of responsibility, it stipulates, in enumerating the duties of the Secretary, that he shall discharge them "under the direction of the President and the Board of Directors." If a future Secretary should be inefficient, the Board and not the membership would be blamed for his shortcomings, and yet, while the Board is responsible for the performance of his duties, it is not responsible for his selection. It is to remove this anomaly that the amendment is unanimously recommended to the membership. It was proposed last year, when there was considerable misunderstanding as to its effect upon Mr. Pope. In spite of this, 70.3 per cent of the votes cast were in favor of it, showing that its reasonableness appealed to the membership. The constitution requires 75 per cent. The misunderstanding in regard to Mr. Pope has been most happily removed by the Board's appointing him Honorary Secretary at full salary, and the amendment is brought forward again on its merits.

The Board's interim appointment of Mr. Hutchinson, which was so overwhelmingly confirmed by the recent nominations of the members, indicates the Board's sense of responsibility in the important question of Secretary.

The National Electric Light Association, the American Society of Mechanical Engineers, the American Society of Civil Engineers and all important business corporations find that the election of a Secretary by the Board, to which he is responsible, contributes to efficiency. The nearer the Institute comes to being managed on an efficient business basis the greater will be the benefits it can give to its members and the greater will be its importance as a national body.

Respectfully submitted,
BOARD OF DIRECTORS,
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.
March 21, 1912.

Report of Committee of Tellers on Nomination Ballots

To the Board of Directors, American Institute of Electrical Engineers.

Gentlemen: This Committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute, for 1912–1913. The result is as follows:

Total number of envelopes said to contain ballots received from Secretary		1174
Envelopes not containing ballots	33	
Rejected on account of bearing no identifying name on outer envelope	32	
Rejected on account of having reached the Secretary's office after February 29	67	
Rejected as a duplicate (two ballots received from the same voter, in which case ballot last received was counted)	1	
	—	133
Leaving as valid ballots		1041

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

Ralph D. Mershon	927
*Scattering	57
Blank	57
Total	1041

*Divided among 21 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these 57 votes is shown on the original tally sheets filed in the Institute office.

FOR VICE-PRESIDENTS

William S. Murray, New Haven, Conn	739
Arthur W. Berresford, Milwaukee, Wis.	704
Henry H. Norris, Ithaca, N. Y.	636
Harry E. Clifford, Cambridge, Mass.	560
S. D. Sprong, Brooklyn, N. Y.	136
*Scattering	69
Blank	279
Total	3123

*Divided among 50 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these 69 votes is shown on the original tally sheets in the Institute office.

FOR MANAGERS

Comfort A. Adams, Cambridge, Mass.	555
Ernst J. Berg, Urbana, Ill.	550
William B. Jackson, Chicago, Ill.	523
Frederick Bedell, Ithaca, N. Y.	450
Lewis T. Robinson, Schenectady, N. Y.	399
S. M. Kintner, Pittsburg, Pa.	286
J. Franklin Stevens, Philadelphia, Pa.	277
William McClellan, New York	253
H. St. Clair Putnam, New York	252
W. F. Wells, Brooklyn, N. Y.	38
*Scattering	132
Blank	449
Total	4164

*Divided among 86 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these 132 votes is shown on original tally sheets in Institute office.

FOR TREASURER

George A. Hamilton	853
Scattering	14
Blank	174
Total	1041

FOR SECRETARY

F. L. Hutchinson	960
Scattering	8
Blank	73
Total	1041

Respectfully submitted,
H. W. FLASHMAN, *Chairman.*
FREDERICK BORCH.
BENJ. K. BOYCE.
ROBERT MORRIS.
WM. C. YATES.
Committee of Tellers.
March 5, 1912

Report of Committee on Code of Principles of Professional Conduct

To the Board of Directors, A.I.E.E.

Gentlemen: In accordance with the instructions of the Board of Directors, at the meeting of February ninth, the Committee on Code of Principles of Professional Conduct herewith reports its final draft for the action of the Board (See page 447, Section II). This draft, as provided for by the Board, embodies a number of modifications suggested since the last meeting, and, while further changes could undoubtedly be made, the committee feels the present draft is in a form that will meet the approval of the membership and will reflect credit upon the Institute.

At the time this year's committee took up the work of revising and producing a suitable Code, the sentiment of the membership was very generally known as a result of the work of the previous committee, and it was felt that if there were created a jury of eighteen leading members of the Institute in whose hands, together with those of the committee, the Code could be left, the result would undoubtedly be conservative and expressive of the Institute's best traditions and ideals.

This jury consisted of the following members, acting as advisory members of the committee: William S. Barstow, Louis Bell, John J. Carty, Francis B. Crocker, Dugald C. Jackson, A. E. Kennelly, John W. Lieb, Jr., C. O. Mailloux, Ralph D. Mershon, Henry H. Norris, Ralph W. Pope, Harris J. Ryan, Charles F. Scott, Samuel Sheldon, William Stanley, Lewis B. Stillwell, Elihu Thomson, and W. D. Weaver.

The committee consists of: Messrs. George F. Sever, chairman; Harold W. Buck, Samuel Reber, Charles P. Steinmetz, Henry G. Stott, and Schuyler Skaats Wheeler.

The Code as presented has the unanimous approval of all the members of the committee, and the approval of all of the advisory members excepting Messrs. Barstow, Mailloux, Mershon, and Stillwell, as follows:

APPROVING THE CODE

Louis Bell,
Harold W. Buck,
John J. Carty,
Francis B. Crocker,
Dugald C. Jackson,
A. E. Kennelly,
John W. Lieb, Jr.,
Henry H. Norris,
Ralph W. Pope,
Samuel Reber,
Harris J. Ryan,
Charles F. Scott,
George F. Sever,
Samuel Sheldon,
William Stanley,
Charles P. Steinmetz,
Henry G. Stott,
Elihu Thomson,
W. D. Weaver,
Schuyler S. Wheeler.

DISAPPROVING THE CODE

William S. Barstow,
C. O. Mailloux,
Ralph D. Mershon,
Lewis B. Stillwell.

Mr. Stillwell's criticisms were presented in full at the last meeting of the Board, since which the draft has been considerably modified out of respect to them.

Mr. Mershon's criticisms were duly mailed to each member of the Board on March first, and have been carefully considered by the committee, which has respected as many of them as was possible.

Most careful attention has also been given to the criticisms of Mr. Thomas, who, though not a member of the committee or of the advisory committee, has deeply interested himself in the Code. A number of the valuable suggestions of Mr. Thomas have been incorporated in the draft herewith presented.

The criticisms of Mr. Mailloux in respect to the earlier provisions regarding Standards, and the disagreement between the subject-matter of the Code and its title, were met by eliminating all reference to Standards and by changing the name of the Code from Ethics to Principles of Professional Conduct.

Mr. Barstow's objections are largely that a code is undesirable.

A large part of such criticism of the Code as has been adverse appears to be due to the point of view that the Institute's Code should be like the codes of several other societies, principally societies of consulting engineers, in being sufficiently rigid to become incorporated into the constitution of the society, and to enable penalties or expulsion to be called for in case of violation. The Code herewith presented has not been written with this object in view, but with the object of crystallizing into definite expression an already existing sentiment, and of setting up a standard that shall be educational as well as admonitory.

The Committee recognizes that the Institute's first Code could not be rigid, but that, as the Standardization Rules have developed through successive years under the guidance of a proper standing committee, in the same way the Code of Principles of Professional Conduct may be expected to develop. It would be impracticable to submit the Code to the vote of the whole membership for the same reasons that it has been found impracticable to submit the Standardization Rules to the same vote. If submitted to the vote of the membership, the frequent changes necessary for growth would be very seriously hampered.

The fact that the Code is the product of a group of leading members of the Institute, including, if it is adopted, the Board of Directors, is, in the opinion of the committee, a sufficient guarantee that it is in accord with and represents the ideas of the membership in the same way the Standardization Rules represent them.

The majority in support of the Code is larger than might have been expected in a work involving accommodation to so many different points of view as exist in the composite membership of the Institute and come to the surface in connection with a matter that is so much one of opinion as is a code of professional conduct.

The committee feels justified in regarding the present Code as corresponding to the standard and ideals of such a preponderating majority of the membership of the whole Institute that its adoption by the Board of Directors would be but putting the seal of approval upon and recognizing the unwritten code of conduct that already exists in the Institute. In concluding this report, the committee would quote from the letter of a member of the advisory committee, which says: "I do not think that objections to one or two of the features of the Code should stand in the way of its general approval. Such objections could be raised against the United States Constitution or any other document."

Respectfully submitted,
GEORGE F. SEVER, *Chairman.*
New York, March 6, 1912.

P. S. There is no space to quote from all the letters that have been received in support of the Code; the Committee appends a few extracts.

Mr. William Stanley:

". . . It seems to me that the draft you have submitted to me is well drawn up, is desirable, and should be adopted. Of course, it is a big subject, and it is impossible to cover all of the many trivial points that can be brought up, as it is almost a moral question; but I think the brief statement forwarded to me is admirably adapted to crystallize sentiment on these matters."

Dr. Louis Bell:

". . . I think the Code as a whole will meet the approbation of the engineering public, and it certainly is proceeding along the right lines."

Dr. Elihu Thomson:

"I have received final draft of the report on Code of Principles of Professional Conduct. I entirely approve of the report as in form for submission to the Board of Directors next Friday."

Dr. A. E. Kennelly:

". . . The report as it stands has my hearty approval, which I am also communicating to Colonel Reber and Secretary Hutchinson, as requested. . . ."

Prof. Francis B. Crocker:

"I thoroughly approve of the Code of Principles of Professional Conduct that is now under consideration by the Institute. . . . I do not think that objections to one or two of the features of the Code should stand in the way of its general approval. Such objections could be raised against the United States Constitution or any other document."

Prof. Harris J. Ryan:

" . . . I consider it to be a most excellent document in every way. I approve it heartily, and I trust that it will be promptly adopted and promulgated by the Institute."

Mr. J. W. Lieb, Jr.:

" . . . I beg to say that I have given the proposed draft careful consideration, and it has my hearty endorsement. While the proposal as submitted does not perhaps contain all that it may be desirable to incorporate in the Code eventually, it is, in my judgment, a good start, meets satisfactorily the ground covered, and has my entire approval."

A. I. E. E. Meeting in New York, March 8, 1912

The two hundred and sixty-ninth meeting of the A. I. E. E. was held in the Engineers Building, New York, Friday evening, March 8, 1912. President Dunn, in calling the meeting to order at 8:15 o'clock, made announcement of the Directors' Nominees selected at the Board meeting that afternoon, and that the Board of Directors had adopted the Code of Principles of Professional Conduct. President Dunn then introduced Mr. David B. Rushmore, chairman of the High-Tension Transmission Committee, under whose auspices the meeting was being held.

Mr. Rushmore introduced Mr. Charles W. Stone, who, on account of the illness of Dr. Steinmetz, read the paper which the latter had prepared for the meeting, on " Some Problems of High-Voltage Transmission."

President Dunn then introduced Mr. E. M. Hewlett, who presented in abstract his paper entitled " Characteristics of Protective Relays." The President, speaking of the importance of the work done in high tension-transmission by members of the Institute, called for a discussion of the two papers together, which was participated in by Messrs. David B. Rushmore, C. S. Ruffner, F. W. Peek, Jr., Percy H. Thomas, A. E. Kennelly, A. S. McAllister, Farley Osgood, W. S. Murray, C. O. Mailloux, C. C. Badeau, E. M. Hewlett, and Charles W. Stone.

After the close of the discussion President Dunn spoke again on the subject of the amendments to the Constitution, urging a full vote on the matter, and a careful study of the purport of the changes, since it had been found that the opposition of some members was due to a misunderstanding of what the amendments really sought to secure.

Annual Banquet of the Pittsburgh Section of the A.I.E.E.

The annual banquet of the Pittsburgh Section of the A.I.E.E, held Saturday evening, February 17, in the large banquet hall of the Fort Pitt Hotel, was the largest and most successful ever held by this organization, over 400 members and their friends being present.

The speech-making was started by Mr. K. C. Randall, Chairman of the local section, who, in a few words, introduced the toastmaster, Mr. L. A. Osborne.

The guest of honor and first speaker was President Gano Dunn of the Institute, who responded to the toast, " The Electrical Engineer." President Dunn spoke of the wonderful accomplishments of the electrical engineer. He then proceeded to pay tribute to Pittsburgh, and said that what it had accomplished was a great monument to engineering. George Washington, a great civil engineer, visited the site of Pittsburgh three times and had the Government send out a commission which caused a city to be founded here. The many virtues possessed by the immortal Washington cause us often to forget that first of all he was an engineer, and a great one.

The A.I.E.E., he said, is feeling more and more the sense of its own responsibility and it owes its growth to the work of the Sections like the one in Pittsburgh.

The next speaker was Dr. Hammerschlag, Director of the Carnegie Technical Schools, who spoke on "The Value of an Expert," in solving general human problems. Where to get experts is the question. On the educational institutions devolves the burden. From these a school of experience is destined to emerge. The A.I.E.E. aids by educating engineers, but coordination is needed. Engineers should take part in the settlement of world problems and those that tend to the solution of world problems.

Mr. A. Leo Weil, president of the Voters League of Pittsburgh, who has been very prominent in the civic improvement of the city, spoke on "The Electrical Development in Modern Municipal Conditions."

The last speaker of the evening was Mr. H. E. Longwell, who proved to be the humorist of the evening, taking for his subject "Cultural Studies and their Value to the Engineer." Mr. Longwell spoke of the value of Latin and Greek to the engineer, and in a humorous vein mentioned many of the dead language phrases familiar in engineering parlance.

The arrangements for the banquet were carried to very successful termination by Mr. K. C. Randall, Chairman, and Mr. E. L. Farrar, Secretary, assisted by the committee consisting of Messrs. R. W. Atkinson, R. V. Bingay, R. S. Feicht, E. Friedlaender, S. P. Grace, and E. P. VanKirk.

United Engineering Society

TREASURER'S REPORT

To the Board of Trustees,
United Engineering Society.

I beg to submit herewith the report of your Treasurer as of December 31, 1911.

I. FINANCES

As shown by the balance sheet submitted herewith, the physical property of the United Engineering Society, over and above the value of the building and the equity in the land, consists of building equipment amounting in value to $25,037.72, furniture and fixtures $5,368.45 and library books $280.62.

During the year 1911 there was added to the Furniture and Fixtures Account an amount representing an expenditure of $1,429.06 including lens for camera in library, telephone booth, two tyepwriting machines for librarian, office furniture for library, canopy and miscellaneous items, and books for the library amounting to $75.36.

The principal of the mortgage on the land held by Andrew Carnegie, Esq., amounting originally to $540,000, has been reduced by payments from the Land and Building Funds of the Founder Societies to $128,000; the American Society of Mechanical Engineers has made further payments during the year of $81,000, bringing its total payments to $180,000, the full amount of its proportion of mortgage. The American Institute of Mining Engineers has made a further payment of $11,000, reducing the balance due from it to $74,000. The American Institute of Electrical Engineers balance of mortgage amounts to $54,000.

The gross operating expenses for the year 1911 were $38,279.35, an increase over the year 1910 of $3,773.10, mainly due to an augmented pay-roll.

In accordance with a resolution of the Board at the meeting held on January 26, 1911, an appropriation of $5,000 was made out of the surplus for the year 1910 and of this amount $4,933.75

was invested in the Delaware & Hudson Company four per cent bonds as an addition to the Contingency and Renewal Fund, as provided for in the Founders Agreement, bringing the invested amount of the Reserve Fund up to $20,265. It is recommended that a similar appropriation be made out of the available balance from this year's operations which will then show a balance to be added to Surplus Account of $9,979.75.

The assessments paid for the year 1911 by the Founder Societies, each occupying one entire floor, were $4,500 each, representing a total expenditure by each, including interest on its full principal of mortgage on land, of $11,700, reduced in each case to the extent the Society may have paid off part of its mortgage share. As the Associate Societies are assessed approximately $10,000 for equivalent facilities, it will be seen that the Founder Societies are still carrying more than their proportion of the carrying charges for equivalent office space occupancy in the building.

II. Building

Equipment: During the year 1911 the Real Estate Equipment Account has been increased to an extent of $6,270 chiefly due to the expense of $6,196 incurred in installing the mezzanine balcony in the main library (authorized by the Board, April 27, 1911). This increased equipment is fully recognized as a useful and aesthetic addition.

There was also installed on the passenger elevators the much-needed hotel annunciator signal-system, at a cost of $1,500. The wisdom of this installation is reflected in the reduction of the cost of elevator service from $5.81 per day in 1910 to $4.30 per day in 1911—a saving of $1.51 per day.

Office Occupancy: Attention is called to the fact that on January 1, 1912, there was no unoccupied floor space devoted to office use in the building, but that there were three rooms vacant on the 12th floor (former occupancy value of $2,000) originally designed for a museum, but first used as a storage by the Founder Societies, and later for occupancy as a lecture-room by the Columbia University Extension Course in Architecture. These rooms have been vacant since July 1, 1911, but have been temporarily used by the library staff during the installation of the mezzanine gallery and alterations in the main room of the library.

Meetings or Lectures: The record of the number of times the rooms were used during 1911 for meetings or lectures (not for office occupancy) is:

MEETINGS IN ENGINEERS BUILDING DURING 1911.

Meeting Room	Number of times occupied		
	1910	1911	Change
Auditorium 3rd and 4th floors...............	36	44	8 more
No. 1 Assembly Room 5th floor...............	25	40	15 "
No. 2 " " 5th "	53	54	1 "
Lecture Room No. 5 ...6th "	39	34	5 less
" " " 6 6th "	21	7	14 "
" " " 7 6th "	1	0	1 "
" " " 8 6th "	63	86	23 more
Small Committee Room 2nd "	38	26	12 less

During the year 1911 the facilities of the building were enjoyed by 48 Societies holding a total of 251 meetings, with an attendance of 42,400, as contrasted with the same number of meetings—251—during 1910, with an attendance of 30,722; a gain in attendance for 1911 of 11,678.

Beginning May 1, 1911, Lecture Room No. 6 was withdrawn from use as a lecture room and utilized for office occupancy.

III. LIBRARY

During the year 1911 there were added to the Library of the three Founder Societies and the United Engineering Society 2,590 volumes and pamphlets, making a total of 47,500 volumes and pamphlets in the library.

The increase in attendance is particularly gratifying, being 11,014 in 1911 as compared with 9,320 in 1910—an increase of more than 18 per cent.

The new department of research work is being developed as rapidly as the size of present force will permit. One hundred and forty-three searches were made, and copies of the references preserved for general use. The requests for researches have been largely by correspondence from Japan, South Africa, Australia, Canada, England, and different parts of the United States. The Library receives more than 700 technical periodicals which are available for this special reference-work.

The construction of the mezzanine gallery, authorized by the Board of Trustees of the U. E. S., May 27, 1911, has increased the capacity of the shelves about 10,000 volumes, and has added materially to the appearance of the room.

There are also on file with the Treasurer the following additional schedules, comprising information of special interest only, which are available for consultation:

Trial Balance, December 31, 1911.

Trial Balance, January 1, 1912.

Accounts Receivable, December 31, 1911.

Accounts Payable, December 31, 1911.

Library Adjustment Account, December 31, 1911.

Furniture and Fixture Account, Year 1911.

Detailed Operating Account, Year 1911.

Respectfully submitted,
Jos. STRUTHERS,
Treasurer.

Associates Elected March 8, 1912

ALLING, SYDNEY, Engineering Department, Rochester Railway & Light Co.; res., 44 Vick Pk., B., Rochester, N. Y.

ALTAMIRANO, SALVADOR E., Professor of Mechanical Engineering, National University of Mexico, Mexico, D. F.

ANDERSON, BERTHIL, Chief Inspector of Electricity, City Hall; res., 66½ Grand Ave., Portland, Ore.

ANDREWS, JAMES HENRY MILLAR, Superintendent of Lines and Cables, Philadelphia Rapid Transit Co.; res., 820 Dauphin St., Philadelphia, Pa.

AXEL, SWEN, Designing Engineer, Electro-Magnetic Tool Co., 115 So. Clinton St.; res., 1009 South Oakley Blvd., Chicago, Ill.

BACON, JOHN LEWIS, JR., Equipment Man, American Telephone & Telegraph Co., 192 Benefit St., Pawtucket, R. I.

BARBER, ROBIN HEMAN, Sales Engineer, Century Electric Co., Room 322, Monadnock Bldg., Chicago, Ill.

BENEDICT, ARTHUR IGNATIUS, Motor Salesman, Holtzer-Cabot Electric Co. Chicago, Ill.

BLISS, ERNEST FRED, JR., Draughtsman, New York Railways Co.; res., 135 E. 49th St., New York, N. Y.

BRADLEY, CLARENCE LUIN, Engineer, McCabe & Bradley, Room 35 Harrell Bldg.; res., 420 N. Court St., Visalia, Cal.

BRANSON, WALTER J., Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburg; res., 427 Center St., Wilkinsburg, Pa.

BUCHAN, PERCY HALCEO, Engineer's Assistant, British Columbia Elec. Ry. Co., Ltd.; res., 1114 Barclay St., Vancouver, B. C.

BUCKS, HERBERT RAYMOND, Chief Electrician, Oregon Short Line R. R. Co., Rm. 227 Deseret News Annex, Salt Lake City, Utah.

BURNHAM, WILLIAM ALLDS, Assistant to Master Mechanic, Elevated Roads of Chicago, 518 Royal Insurance Bldg., Chicago, Ill.

CARTER, FRANCIS ERVEN, Operating Superintendent, Pennsylvania Water & Power Co., Holtwood, Pa.

CHASE, PHILIP HARTLEY, Electrical Engineer, Public Service Electric Co., 27 Mechanic St.; res., 31 East Park St., Newark, N. J.

CLARKE, DAVID DANIEL, Assistant Electrical Engineer, Kansas City Electric Light Co.; res., 1629 Benton Blvd., Kansas City, Mo.

CROMWELL, LEWIS WARHAM, Chief Electrician, Havana Electric Railway Co.; res., Salud 40 Altos, Havana, Cuba.

CROSBY, THOMAS HAROLD, Demonstrator, Electrical Engineer Dept., University of Toronto, Toronto, Ont.

CUNDELL, ARTHUR BARNES, Salesman, Small Motor Dept., General Electric Co., West Lynn, Mass.

DAWES, CHESTER LAURENS, Assistant, Division of Engineering, Harvard University, Cambridge, Mass.

DEAN, HAROLD CHURCHILL, Checker & Inspector, Engineering Dept., Public Service Co. of Northern Illinois, 137 So. La Salle St., Chicago, Ill.

DEMPSEY, WILLIAM T., General Foréman, Arc Lamp Dept., New York Edison Co., 117 West 39th St., New York, N. Y.

DORSZESKI, VICTOR ARTHUR, Assistant to W. J. Hagenah, 613 First National Bank Bldg.; res., 1927 N. California Ave., Chicago, Ill.

DUNCAN, CORBIN MARSHALL, Manager, State Bank Building Co., 610 State Bank Bldg., Little Rock, Ark.

DURGIN, WILLIAM ANDREW, Assistant Chief Testing Engineer, Commonwealth Edison Co.; res., 6357 Jackson Ave., Chicago, Ill.

EDDY, LLOYD CHAMPLIN, Engineering Assistant, New York Telephone Co., 15 Dey St.; res., 68 West 56th St., New York, N. Y.

EDGE, DEXTER, Operating Department, American Sheet & Tin Plate Co., 1318 Frick Bldg., Pittsburgh, Pa.

EMERY, FRANK OSCAR, Electric Meter Expert, Madison Gas & Electric Co., 126 E. Main St.; res., 1124 Jenifer St., Madison, Wis.

FELLER, CHARLES VICTOR, Student Engineer, General Electric Co.; res., 618 Chapel St., Schenectady, N. Y.

FIELD, WILLIAM PERRY, Electrical Engineer, Atlantic Mills; res., 117 Progress Ave., Olneyville, R. I.

FINCH, JOSEPH WESLEY, Chief Electrician, Young Construction Co.; res., 1338 South Grand Ave., Los Angeles, Cal.

FINGADO, REINHARD THEODOR, Assistant Engineer, Mexican Light & Power Co., Ltd.; res., la Merida 2, Mexico, D. F.

FISHER, HARMON FRANCIS, Assistant Professor of Electrical Engineering, University of California; res., 2811 Parker St., Berkeley, Cal.

FLEET, ARTHUR H., Electrical Engineer, Cutler-Hammer Mfg. Co.; res., Hotel Aberdeen, Milwaukee, Wis

FLEMING, ROBERT FLEMING, Erecting and Testing Dept., with Henry R. Worthington, Harrison, N. J.

FOLTZ, LEROY STEWART, Operating Engineer, Illinois Traction Co.; res., 228 West Adams St., Springfield, Ill.

FRIED, JEROME ARTHUR, Instructor, Mechanical Engineering Dept., Sibley College, Cornell University; res., 129 Waite Ave., Ithaca, New York.

FULLER, FLOYD MERRILL, Northern Equipment Co., Duluth, Minn.

FULTON, HOMER HARVEY, Superintendent of Equipment, Oakland & Antioch Ry., Concord, Cal.

Gillon, Gustave, Professor of Electrical Engineering, University of Louvain; res., 5 rue des joyeuses Entrees, Louvain, Belgium.

Godfrey, Frank Ozro, Testing Engineer, Commonwealth Edison Co., 28 N. Market St.; res., 3915 Congress St., Chicago, Ill.

Goldmerstein, Leon, American Society of Mechanical Engineers; res., 200 West 41st St., New York, N. Y.

Gray, George Harrison, Engineering Dept., Telluride Power Co., Provo, Utah.

Growdon, James Paul, Foreman Electrical Construction, Portland Railway Light & Power Co., River Mill Station, Estacada, Ore.

Hart, Richard Ambrose, Drainage Engineer, U. S. Dept. of Agriculture, 1108 Boston Bldg., Salt Lake City, Utah.

Highland, Caswell, Ontario Power Co. Niagara Falls, Ont.; res., 366 First St., Niagara Falls, N. Y.

Hilton, Everett George, Wire Chief, Central District & Printing Tel. Co.; res., 320 West 6th St., East Liverpool, Ohio.

Hoge, John Cameron, Assistant Engineer, Office of City Engineer; res., 2646 Sumner St., Lincoln, Neb.

Holmes, John Dewing, Manager, Home Tel. & Tel. Co., 68 N. Raymond Ave.; res., 600 N. Fair Oaks Ave., Pasadena, Cal.

Holt, Carroll, Meter Chief, Fayettville, Electric Co., Fayettville, Ark.

Hooper, William Ellsworth, Distribution Dept., Mexican Light & Power Co.; res., 6a Versalles 103, Mexico, D. F.

Hopkins, Mark Luman, R.F.D., 1, Minneapolis, Minn.

Houghton, Albin J., Jr., Draftsman, San Diego Gas & Electric Co., San Diego; res., 700 First St.. Coronado, Cal.

Hull, Stanley W., Designing Engineer, Clark Electric Co., 149 Broadway; res., 602 West 135th St., New York, N. Y.

Humphreys, Alexander Crombie, President, Stevens Institute of Technology, Hoboken, N. J.

Hutson, Miles Brewton, Salesman. Electric Appliance Co.; res., 721 Lowerline St., New Orleans, La.

Jacoby, Louis, Salesman, Westinghouse Electric & Mfg. Co. of Texas, 701 First National Bank Bldg., Houston, Texas.

Janney, Joseph Allison, Jr., Sales Agent, General Electric Co., 30 Church St., New York,.N. Y.; res., 644 Salem Ave., Elizabeth, N. J.

Johnson, Clayton Oscar, Superintendent, City Lighting Plant; res., 711 West 8th St., Jamestown, N. Y.

Jones, Charles H., Assistant Engineer, Electrical Dept., Chicago Elevated Railroad Companies, 160 Jackson Blvd., Chicago, Ill.

Katsuno, Sadaharu, Electrical Engineer and Assayer, Ferro and Acid Tungsten Co.; res., 21 Tamuracho Shiba, Tokyo, Japan.

Kilner, Ralph Hammond, Mechanical Engineer, Westinghouse Electric & Mfg. Co., 1420 New York Life Bldg., Chicago, Ill.

Kirkpatrick, John G., Commercial Salesman, 99 Leonard Ave., Ashland, Ore.

Kite, James Moir, Engineer, Division Telegraphs & Telephones, Public Service Commission, 2d Dist.; res., 92 Willitt St., Albany, N. Y.

Krausnick, Walter S., Engineering Dept., Wagner Electric Mfg. Co.. 6400 Plymouth Ave.; res., 4117 Magnolia Ave., St. Louis, Mo.

Lane, Howard Sumner, Assistant to Superintendent Electric Distribution, Pacific Gas & Electric Co., res., 2421 Fulton St., Berkeley, Cal.

Larner, Chester Waters, Hydraulic Engineer, Wellman-Seaver-Morgan Co.; res., 2040 Stearns Road, Cleveland, Ohio.

Lent, Wilmar Francis, Superintendent, Passaic Metal Ware Co.; res., 272 Lafayette Ave., Passaic, N. J.

Lyon, Robert Ray, 2d Lieutenant, Coast Artillery Corps, United States Amry, Fort Terry, N. Y.

Marriner, Alfred Warrington Edwin, Salesman, Northwestern Electric Co., 611 W. Adams St., Chicago, Ill.

Mattison, Wilbur De Forest, Traveling Salesman, W. R. Ostrander & Co., 22 Dey St., New York; res., 166 Calyer St., Brooklyn, N. Y.

May, Richard Bascom, Salesman, Westinghouse Electric & Mfg. Co., Traction Bldg., 2160 Grand St., Walnut Hills, Cincinnati, Ohio.

McKenzie, Lauren Frederick, Salesman, Westinghouse Electric & Mfg. Co., 27 Woodward Ave.; res., 108 Charlotte Ave., Detroit, Mich.

Metz, Louis Charles, Assistant to Engineer, Bell Telephone Co. of Penn., 1230 Arch St.; res., 2059 Franklin St., Philadelphia, Pa.

Mills, James Leonard, Electrical Engineer, Illinois Steel Co., 1319 Wabansia Ave.; res., 817 South Claremont Ave., Chicago, Ill.

Milton, Ivan L., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

Mode, Halford Louis, Designing Engineer, General Electric Co.; res., 25 Hawthorne St., Lynn, Mass.

Morice, John Henry, Electrical Engineer, General Electric Co.; res., 24 Swan St., Schenectady, N. Y.

Moser, George, Electrical Engineer, Copper Extraction Co.; res., Montana Hotel, Anaconda, Mont.

Murphy, Harry Almon, Salesman, Butte, Electric Supply Co., 44 East Broadway, Butte, Mont.

Pendergast, Roland Ball, Assistant Engineer, Stone & Webster Engineering Corp'n., 147 Milk St.; res., 48 Beacon St., Boston, Mass.

Pierce, Paul Harold, Research Telephone Engineering, Western Electric Co., 463 West St., res;. 111 West 12th St., New York, N. Y.

Piper, Franklin Samuel, Electrician, Manchester Traction, Light & Power Co.; res., 115 Jewett St., Manchester, N. H.

Plimpton, Raymond Evans, Engineering Student, General Electric Co.; res., 70 Moulton St., West Lynn, Mass.

Roberts, William Jesse, Manager, Roberts Electrical Repair Co., 248 Hosea Ave., Cincinnati, Ohio.

Rose, Herbert, Secretary-Treasurer, Scott-Rox Company, 1651 Marquette Bldg.; res., 854 Lakeside Pl., Chicago, Ill.

Ryder, Robert Weir, Professor of Electrical and Mechanical Engineering, California Polytechnic School, San Luis Obispo, Cal.

Rylander, John Leonard, Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh; res., 609 9th Ave., Irwin, Pa.

Salkeld, Alvirtis Santford, Commercial Engineer, General Electric Co.; res., 15 Mynderse St., Schenectady, N. Y.

Schooley, Claude O., Electrical Engineer, Westinghouse Electrical & Mfg. Co., Pittsburgh; res., 415 Ross Ave., Wilkinsburg, Pa.

Shackelton, William James, Telephone Engineer, Western Electric Co.; res., 48 West 94th St., New York, N. Y.

Sharp, Augustus William, Jr., Fort Wayne Electric Works, 623 Marquette Bldg.; res., 3125 West Monroe St., Chicago, Ill.

Shearer, Harry Alfred, District Engineer, Pacific Tel & Tel. Co.; res., 286 11th St., Portland, Ore.

Shipeck, Adolph, Assistant Electrical Engineer, Seattle Electric Co.; res., 3840 Linden Ave., Seattle, Wash.

Small, Fred Fulton, Mechanical Engineer, Pacific Electric Ry. Co.; res., 449 Harvard Blvd., Los Angeles, Cal.

Smith, George Barnett, General Superintendent, Electrical Dept., Electric Power Co., Ltd., Belleville, Ont.

Speyer, Harry Robert, Electrical & Mechanical Engineer, 2 New China Bazaar St., Calcutta, India.

Stevens, Frederic Warde, Sales Engineer, Allis-Chalmers Co., 1031 Maison Blanche, New Orleans, La.

Stevenson, Robert Lewis, Instructor, Cornell University, Ithaca, N. Y.

Stewart, Elbert Davis, Salesman & Engineer, Westinghouse Electric & Mfg. Co., Dallas, Texas.

Stone, Clarence George, Jr., Student, Columbia University; res., 273 Rich Ave., Mt. Vernon, N. Y.

Stringfellow, Harris Martyn, Civil Engineer, Mexico Tramways Co.; res., Avenida Paris 23, Mexico City, Mex.

Sullivan, Herbert Ignatius, Electrician, Bay State Street Railway, Quincy; res., 6 Willis St., Dorchester, Mass.

Tassie, Robert Wilson, Electrical Engineer, Havana Electric Railway Co.; res., Prado 3, Havana, Cuba.

Thayer, Edward Sprague, Telephone Engineer, Pacific Tel. & Tel. Co., 310 Commercial Club Bldg.; res., 1345 Wistaria Ave., Portland, Ore.

Thayer, Henry Spafford, Electrical Engineer, Hazard Mfg. Co., 552 West Adams St.; res., 4446 Sidney Ave., Chicago, Ill.

Thorp, Theron Alberto, Electric Time Service Inspector, Western Union Telegraph Co., 109 State St., Boston, Mass.

Unland, Harry Lloyd, General Electric Co.; res., 1118 Campbell Ave., Schenectady, N. Y.

Van Norman, George Sydnor, Chief Electrician, Detroit Copper and Brass Rolling Mills; res., 160 Regular Ave., Detroit, Mich.

Waldman, Carl Andrew, Telephone Engineer, Pacific Tel. & Tel. Co.; res., 393 Marguerite Ave., Portland, Ore.

Whitehurst, Raymond F., Jr., Electric Meter Tester, Southern Pacific Co., San Francisco; res., 1317 Webster St., Oakland, Cal.

Willard, Lewis Leigh, Chief Engineer, W. J. Rainey Estate, Uniontown, Pa.

Wilson, Roy Gillett, Electrical Engineer, Fort Dodge Portland Cement Co., Gilmore City; res., Humboldt, Iowa.

Wright, George R., Salesman, Canadian General Electric Co.; res., 1380 Thurlow St., Vancouver, B. C.

Wright, James Chester, Telephone Engineer, Western Electric Co., 463 West St.; res., 48 W. 94th St., New York, N. Y.

Wulsin, Lucien, Jr., Stone & Webster Engineering Corp'n., 247 Newbury St., Boston, Mass.

Wyman, Frank Thomas, Chief Electrical Engineer, Pittsburgh Transformer Co.; 2217 Federal Extension, N. S., Pittsburgh, Pa.

Total, 118.

Associates Transferred on March 8, 1912

The following Associates were transferred to the grade of Member in the Institute at the meeting of the Board of Directors held on March 8, 1912.

Edward H. Everit, Chief Engineer, Southern New England Telephone Co., New Haven, Conn.

Frederick W. Ells, Secretary and Engineer, Northwestern Manufacturing Company, Milwaukee, Wis.

L. A. Osborne, Vice-President, W. E. and M. Company, Pittsburgh, Pa.

Nicholas Stahl, Commercial Engineer, W. E. and M. Company, Pittsburgh, Pa.

Nathan Hayward, Chief Engineer, Bell Telephone Company of Penn., Philadelphia, Pa.

George L. Hoxie, Consulting Engineer, 50 Church Street, New York.

Clayton H. Sharp, Test Officer, Electrical Testing Laboratories, 80th Street and East End Avenue, New York.

Alexander C. Humphreys, President, Stevens Institute of Technology, Hoboken, N. J.

Carl J. Fechheimer, Electrical Engineer, Crocker-Wheeler Company, Ampere, N. J.

Recommended for Transfer March 5, 1912

The following Associates were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on March 5, 1912. Any objection to the transfer of any of these Associates should be filed at once with the Secretary:

Frank F. Fowle, Consulting Electrical Engineer, Chicago, Ill.

Julien E. Dalemont, Consulting Electrical Engineer, Montreal, P. Q.

Maurice N. Blakemore, Assistant to Manager Engineering Reports, J. G. White and Company, New York.

John B. Klumpp, Inspecting Engineer, Philadelphia, Pa.

Samuel H. Rippey, Consulting Engineer, Philadelphia, Pa.

L. T. Robinson, General Electric Company, Schenectady, N. Y.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before April 25, 1912.

11212 Kruger, J. L. Brooklyn, N. Y.
11213 Doty, A. J., Mt. Vernon, N. Y.
11214 Throop, G.H., San Francisco, Cal.
11215 Coleman, L. G., Meridian, Miss.
11216 Oliver, C.R., Shelburne Falls, Mass
11217 White, W. P., Schenectady, N. Y.
11218 Pettebone, L. A., Niagara Falls, N. Y.
11219 Wilbur, R. S., Jersey City, N. J.
11220 Oehlmann, C. F., Denver, Colo.
11221 Dodge, C. R. A., Copper Cliff, Ont.
11222 Knight, A. F., Schenectady, N. Y.
11223 Hatten, F. W., Corozal, C. Z.
11224 Kinney, R. M., Berlin, N. H.
11225 Brundige, D. L., Provo, Utah.
11226 Laurencot, H. J., Brooklyn, N. Y.
11227 Peebles, L. H., Columbia, S. C.
11228 Gill, J. H., Schenectady, N. Y.
11229 McCarthy, E. T., Atlanta, Ga.
11230 Holman, A. J., East Orange, N. J.
11231 Murray, J. M., East Orange, N. J.
11232 Chase, S. A., East Pittsburgh, Pa.
11233 Keith, A. E., Hinsdale, Ill.
11234 Harris, C. E., Chicago, Ill.
11235 Cross, F. L., Madison, Wis
11236 Boyer, L., Spearfish, N. D.
11237 Soule, G. F., New Haven, Conn.
11238 Manning, J. J. L., Charlestown, Mass.
11239 McMillan, J. P., Charlotte, N. C.
11240 Butler, E. L., Ellensburg, Wash.
11241 Bird, F. B., Marquette, Mich.
11242 Whyte, H. B., Toronto, Ont.
11243 Folger, R. C., Benson Mines, N.Y.
11244 Chambers, F. H., Buffalo, D. C.
11245 Ahlborn, G. H., Washington, D.C.
11246 Alexander, H. G., Winnipeg, Man.
11247 Benjamin, H. A., Los Angeles, Cal.
11248 Carpenter, C. F. ,Schenectady, N. Y.
11249 Cullen, W. K., San Francisco, Cal.
11250 Donovan, H. A., Winnipeg, Man.
11251 Duffy, R. E., Greenfield, Mo.
11252 Froelich, J. M., Pittsburgh, Pa.
11253 Gerstle, R. J. F., New York, N. Y.
11254 Gibbs, L. D., Boston, Mass.
11255 Harris, L. J., St. Louis, Mo.
11256 Holtzapple, L. H., Winona, Mich.
11257 Kelso, L. E. A., Provo, Utah.
11258 Murray, F. E., Louisiana, Mo.
11259 O'Reilly, R. H., Portage La Prairie, Man.
11260 Pratt, C. C., Salt Lake City, Utah.
11261 Stewart, S. B., Jr., Schenectady, N. Y.
11262 Stockwell, F. C., Hoboken, N. J.
11263 Tabossi, H., Boston, Mass.
11264 Thompson, R.E., Muskogee, Okla.
11265 Wakefield, W. H., Takoma Park, D. C.
11266 Ward, H. I., Muskogee, Okla.
11267 Ward, P. W., Schenectady, N. Y.
11268 Wilber, B. D., Indianapolis, Ind.
11269 Williams, E. F., New York, N. Y.
11270 Gornsted, W. H., Kent, England.
11271 Jones, R.E., Metaline Falls, Wash.
11272 Mason, R., Ampere, N. J.

11273 Mawhinney, H. C., Buffalo, N. Y.
11274 Rost, H. F., Mexico, D. F.
11275 Runge, H. J., Galveston, Tex.
11276 Tear, H. L., Chicago, Ill.
11277 Pierce, T. S., Des Moines, Ia.
11278 Gove, H. S., Tunica, Miss.
11279 Bennett, R. M., New York, N. Y
11280 Stephany, Q., Crystal Falls, Mich.
11281 Roberts, D. H., New York, N. Y.
11282 Lee, L. R., Columbus, Ohio.
11283 Hyer, B. B., Ft. Riley, Kan.
11284 Neely, C., Cripple Creek, Colo.
11285 Quinn, W. J., New York, N. Y.
11286 Meade, J. T., Pt. Chester, N. Y.
11287 Barnes, C. B., Oak Park, Ill.
11288 Buel, F. L., Tepic, Mex.
11289 Faber, J. F., Lockport, N. Y.
11290 Holloway, A. E., Coronado, Cal.
11291 Hopwood, J. M., Jerome, Pa.
11292 Irwin, E., Redlands, Cal.
11293 Kennedy, F. W., Detroit, Mich.
11294 Kilburn, E. D., Rochester, N. Y.
11295 Kneisel, A., Cleveland, Ohio.
11296 Moses, A. L., Chicago, Ill.
11297 Owens, M. F., Hartford, Conn.
11298 Packard, S. D., Schenectady, N. Y.
11299 Padfield, S. E., Helena, Mont.
11300 Schindler, C., Balls Ferry, Cal.
11301 Steels, O. G., Yreka, Cal.
11302 Thomas, C. G. M., Long Island City, N. Y.
11303 Winter, W. H., Montreal, Que.
11304 Wynant, H. W., Uintah, Utah.
11305 Darling, A. R., Indianapolis, Ind.
11306 Rich, M., Chicago, Ill.
11307 Hopkins, B. B., Annapolis, Md.
11308 Miller, O. C., Los Angeles, Cal.
11309 Alexander, G. H., Belvidere, Ill.
11310 Fletcher, J. W., Oak Park, Ill.
11311 Ellis, A. L., Helena, Mont.
11312 Thomson, R. G., Edmonston, Alta.
11313 Morse, V. E., Stanislaus, Cal.
11314 Julian, O. G., New Rochelle, N.Y.
11315 Kearney, G., Prince Rupert, B. C.
11316 Davison, R. T., Vera Cruz, Mex.
11317 Newman, M. L., Pittsfield, Mass.
11318 Payne, L. F., Harrisburg, Ill.
11319 Morehead, W. C., St. Louis, Mo.
11320 Collamore, R., Detroit, Mich.
11321 Jay, W. C., Gatun, C. Z.
11322 McPhee, J. E., Ruskin, B. C.
11323 Gilmore, H. B., Boston, Mass.
11324 Boatright, H. E., San Luis Potosi, Mex.
11325 Kottenbach, E. E., New York, N. Y.
11326 Riley, M. H., Springfield, Ill.
11327 Boyce, F. G., Milwaukee, Wis.
11328 Pope, C. J., East Orange, N. J.
11329 Daniel, R. L, Minneapolis, Minn.
11330 Ridgway, P. H., Seattle, Wash.
11331 Wolff, R. F., Harrisburg, Pa.
11332 McGovern, W. R., Chicago, Ill.
11333 Edgar, L. L., Boston, Mass.
11334 Vosholl, W. H., Wilmerding, Pa.
11335 Kalb, W. C., Lakewood, Ohio.
11336 Braeder, F. A., Newark, N. J.
11337 Johnson, E. F., Pleasant Grove, Utah.
11338 Pollard, L. E., St. Paul, Minn.
11339 Hijar y Haro, J., Aguascalientes, Mex.
11340 Kaelin, F. J., Montreal, Que.
11341 Cary, M., Crystal, W. Va.
11342 Brown, R. D., Pittsburgh, Pa.
11343 Bear, C. S., Bisbee, Ariz.
11344 Cooper, S. B., Pittsburgh, Pa.
11345 Rhett, A. H., New York, N. Y.
11346 Volkmann, W., Jr., Wilkinsburg.
11347 Martin, J. R., Pittsburgh, Pa.
11348 Nathanson, A. S., Oakland, Cal.
11349 Peberdy, W. H., New York, N. Y.
11350 Moore, F., Victor, Colo.
11351 Rohde, W. C. F., Pittsfield, Mass.
11352 Varney, G. E., Indianapolis, Ind.
11353 Winton, R. P., New Haven, Conn.
11354 Crowder, A. N., New Haven, Conn.
11355 Gardiner, H. M., Detroit, Mich.
11356 Kirk, W. L., Canyon Ferry, Mont.
11357 Hoyt, H. C., Schenectady, N. Y.
11358 Besley, S. H., Salt Lake City, Utah.
11359 Carolin, N., New York, N. Y.
11360 McBerty, F. P., Warren, Ohio.
11361 Reid, R. E., Inyo-Kern, Cal.
11362 Shields, H. H., Stanislaus, Cal.
11363 Thornton, E. B., Pittsfield, Mass.
11364 Eaton, G. M., Wilkinsburg, Pa.
11365 Townsend, J. R., Portland, Ore.
11366 Ashmead, E. W., New York, N. Y.
11367 Burchard, A. W., New York, N. Y.
11368 Collar, E. H., Missoula, Mont.
11369 McGarrah, H. S., Scranton, Pa.
11370 Richardson, R. G., Helena, Mont
11371 Siebert, W. A., Great Falls, Mont.
11372 Bull, A. H., Brooklyn, N. Y.

Total, 161

Students Enrolled March 8, 1912

4977 Hagerty, E. M., Polytech. Coll., Eng.
4978 Looney, W. C., Univ. of Texas.
4979 Alexander, R. B., Univ. of Texas.
4980 Greene, O. K., Univ. of Texas.
4981 Mavity, V. T., Purdue Univ.
4982 Howland, P. R., Iowa State Coll.
4983 Houser, T. V., Iowa State Coll.
4984 Hall, O. W., Iowa State Coll.
4985 Brumhall, J. H., Iowa State Coll.
4986 Alexander, P. V., Iowa State Coll.
4987 Rogers, R. R., Iowa State Coll.
4988 Luney, E. A., Iowa State Coll.
4989 Shoemaker, J. J., Iowa State Coll.
4990 Hartung, A. E., Iowa State Coll.
4991 Fischer, E. L., Iowa State Coll.
4992 Gibson, A. D., Iowa State Coll.
4993 Chatburn, G., Iowa State Coll.
4994 Drake, C. P., Iowa State Coll.
4995 Kuempel, R., Iowa State Coll.
4996 Conlee, H. E., Iowa State Coll.
4997 McWilliams, C. O., Iowa State Coll.
4998 Hutchison, C. B., Iowa State Coll.
4999 Clapp, P., Iowa State Coll.
5000 Mead, R. S., Iowa State Coll.
5001 Lieser, H. A., Iowa State Coll.
5002 Berry C. J., Mass. Inst. Tech.
5003 Church, W. G., Texas A. & M. Coll.
5004 Cox, H. T., Texas A. & M. Coll.
5005 Atwell, B. D., Jr., Texas A. & M. Coll.
5006 Elliott, J. S., Rose Polytechnic Inst.
5007 Mayer, E. C., Cornell Univ.
5008 Wineland, J. E., Ohio Northern Univ
5009 Billhimer, F. M., Ohio Northern Univ.
5010 Wolbach, R. H., Lafayette Coll.
5011 Day, G. R. K., Lafayette Coll.
5012 Graham, A. J., Lafayette Coll.
5013 Jefferson, V. E., Lewis Inst. Tech.
5014 Fillmore, G. B., Lafayette Coll.
5015 Case, C. D., De Paul University.
5016 Andrews, C. W., Lafayette Coll.
5017 Boone, H. S., Univ. of Penn.
5018 Cadwallader, J. A., Univ. of Penn.
5019 Rommel, W. C., Univ. of Penn.
5020 Cowan, H. B., Univ. of Penn.
5021 Confesor, V., Univ. of Illinois.
5022 Fager, F. D., Univ. of Illinois.
5023 Lockwood, H. J., Univ. of Illinois.
5024 McEachron, K. B., Ohio Northern Univ.
5025 Snow, W. R., Polytechnic Coll., Eng.
5026 Miller, C. A., Ohio State Univ.
5027 Bouton, E. M., Iowa State Coll.
5028 Shaw, G. R., Iowa State Coll.
5029 Conlee, G., Iowa State Coll.
5030 Roberson, F., Iowa State Coll.
5031 Hopkins, A. L., Iowa State Coll.
5032 Gibson, E. P., Iowa State Coll.
5033 Le Page, F. R., Ohio Northern Univ.
5034 Isakson, A. E., Iowa State Coll.
5035 Pigman, G. R., Purdue Univ.
5036 Richter, O. G., Carnegie Tech. Sch.
5037 Pool, R. H., Ohio Northern Univ.
5038 Magee, J. W., Lafayette Coll.
5039 Cone, D. I., Univ. of California.
5040 Guillon, A. V., Univ. of California.
5041 Sandaval, H. E., Univ. of Cal.
5042 Bridge, A. F., Univ. of California.
5043 Snyder, C. C., Univ. of California.
5044 Ready, L. S., Univ. of California.
5045 Pollard, J. F., Univ. of California.
5046 Howell, R. C., Lafayette Coll.
5047 Griswold, L. E., Carnegie Tech. Sch.
5048 Haigh, P. N., Rose Polytechnic Inst.
5049 Hall, L. C., Polytechnic Coll., Eng.
5050 Belt, J. H., Univ. of Illinois.
5051 Stiefel, I. B., Univ. of Illinois.
5052 Wood, D. C., Univ. of Illinois.
5053 Thornburg, E. R., Iowa State Coll.
5054 Caldwell, J. T., Univ. of Michigan
5055 McIver, M. G., Univ. of Mich.
5056 Bracken, S., Univ. of Nebraska.
5057 Kauffmann, H. P., Univ. of Penn.
5058 McDonald, J. E., De Paul Univ.
5059 Lowd, C. M., New Hampshire Coll.
5060 McFarland, J. L., Texas A. & M. Coll.

Total, 84.

Past Section Meetings

BALTIMORE

An informal dinner attended by 28 members of the Baltimore Section was held at the Hotel Raleigh on the evening of March 1. Professor J. B. Whitehead presided. No formal papers were presented. The proposed amendments to the Constitution were discussed, and met with general approval.

BOSTON

The annual reception and dinner of the members of the engineering societies in Boston and vicinity was held at the Hotel Somerset on January 15, over four hundred engineers being in attendance. Mr. Charles T. Main, president of the Boston Society of Civil Engineers, presided and acted as toastmaster. The speakers were: Professor Ira N. Hollis, president of the Engineering Club; General Hugh Bancroft, chairman of the Directors of the Port of Boston; Professor Wallace C. Sabine, Harvard University; Dr. Richard C. McLaurin, president of Massachusetts Institute of Technology; Dr. Frederick W. Hamilton, president of Tufts College; Admiral Mordecai T. Endicott, president of the American Society of Civil Engineers; Colonel E. I. Meier, past-president of the American Society of Mechanical Engineers; and Gano Dunn, president of the American Institute of Electrical Engineers.

The regular monthly meeting of the Boston Section on February 21 was held in the Edison Auditorium, Chairman Hooper presiding, with an attendance of 85. Mr. H. M. Hobart, consulting engineer for the General Electric Company, Schenectady, presented a paper on "The Relative Costs and Operating Efficiencies of Polyphase and Single-phase Generating and Transmitting Systems." (PROCEEDINGS, February, 1912.)

On February 24, at the invitation of the officers of the Boston Elevated Railway Company, about 300 members of the Boston Section made an inspection trip through the company's new generating station in South Boston, one of the new sub-stations, the new Eliot Square car shops in Cambridge, and the new Cambridge and Beacon Hill Subways. The Company is about to place the new subways into service for the public, but the generating stations and substations have already been in operation for some months.

CLEVELAND

The Cleveland Section held a regular meeting on February 19, in the Chamber of Commerce Library, with an attendance of 38. Chairman B. A. Stowe presided. Mr. Thomas A. Worcester, of the Power and Mining Department of the General Electric Company, Schenectady, read a paper on "High-Tension Transmission Line Equipment," which was illustrated by a large number of slides showing transformers, switches, line construction, and safety devices, and several lightning photographs.

DETROIT-ANN ARBOR

A monthly meeting of the Detroit-Ann Arbor Section was held on February 17, in Employers' Association Hall, Detroit, with Professor C. L. de Muralt in the chair. The paper of the evening, "Illuminating Engineering," was presented by Mr. Ralph Beman of the engineering department of the National Electric Lamp Association. The lecture was illustrated with lantern slides, and took up in turn the subjects of photometric units, sources of light, calculations, and the engineering aspects of illumination. Twenty-five attended the meeting.

FORT WAYNE

The regular meeting of the Fort Wayne Section was held on February 15 at the Fort Wayne Commercial Club, Mr. T. W. Behan presiding. Mr. O. B. Rinehart presented a paper on "Protection of Electric Light and Power Installations," giving a general review of protective devices and describing some of the most recent improvements. The paper was freely discussed by practically the entire meeting, the discussion relating chiefly to lightning protection on high-voltage transmission lines.

LOS ANGELES

The regular monthly meeting of the Los Angeles Section was held on February 20 in the music hall of the Blanchard Building, with Mr. O. H. Ensign in the chair. Mr. Ensign presented a paper on "Gas Power, with Special Reference to Oil Gas Producers in Connection with Electrical Development." The lecture was illustrated with lantern slides. The following took part in the discussion: Messrs. F. C. Mallard, George S. Blankenhorn, F. S. Wade, C. W. Koiner, C. A. Howe, and R. W. Sorensen. Eighty-three members and visitors attended the meeting.

LYNN

The first annual banquet of the Lynn Section was held at the Oxford Club on March 1, and was attended by 128 members and students. Mr. W. C. Fish, general manager of the Lynn Works of the General Electric Company. acted as toastmaster. Mr. Paul M. Lincoln, chairman of the Sections Committee, was the first speaker, and talked on the work the various sections were doing throughout the country. President Gano Dunn gave a talk on polarization, and also discussed the proposed amendments to the Constitution. Mr. E. W. Rice, vice-president and chief engineer of the General Electric Company, and Professor Elihu Thomson, also gave short talks.

MADISON

The Madison Section held a joint meeting on February 16 with the Engineering Society of Wisconsin in the Engineering Building of the University of Wisconsin. Mr. J. N. Cadby presided. A paper on "Relations of Modern Electric Meter Practise to Consumers, State Commissions, and Central Stations," was presented by Mr. F. A. Vaughan, of the firm of Vaughan and Meyer, consulting engineers, Milwaukee. Fifty-one members and visitors attended the meeting.

MILWAUKEE

The regular meeting of the Milwaukee Section was held on February 14, at the Plankinton House, with an attendance of 95 members and visitors. Chairman Vaughan made a report on the work of the Sections Committee at the Chicago Convention and since that time.

The paper of the evening, "Compensated Single-Phase Motors," was presented by Mr. A. H. Timmerman of the Wagner Electric Manufacturing Company of St. Louis. Mr. Timmerman's paper presented a number of curves analyzing the effects on line regulation of varying power factors of motors at the end of the lines. The total regulating effect was divided up into component parts of line loss and generator loss, and it was shown most conclusively that from both standpoints a high power factor would be very advantageous to the central station company. This portion of the paper was followed by curves showing power factors, efficiency, torque and current consumption of the new compensated single-phase commutator type of motor, together with plates showing various schemes of connections and various arrangements for modifying the power factor and the torque to suit the specific load conditions.

The paper was freely discussed, some of the points brought out being the possibility of speed adjustment through a range of approximately 2:1 with the same characteristics as the field-control shunt motors; also that characteristics more or less approaching those of a series motor could be obtained by modifying the proportions. The question of reversibility under good torque conditions was shown to be dependent on the opening of the compensating winding until approximately full speed in the reverse direction had been obtained. Considerable discussion hinged on the possibility of securing dynamic braking with this type of motor, but due to lack of complete tests on this subject no authoritative statement could be made.

MINNESOTA

A meeting of the Minnesota Section was held on February 29 in the assembly room of the Minneapolis General Electric Company. Mr. A. L. Abbott acted as chairman *pro tempore*. A discussion of the meaning of the term

"Good Workmanship and Material" in engineering contracts and specifications was participated in by Messrs. W. I. Gray, contracting engineer, F. H. Overholt, operating engineer, and Charles L. Pillsbury, consulting engineer. A general discussion followed, in which Messrs. Lundquist, Lunt, Harris and Dustin took part.

PHILADELPHIA

The Philadelphia Section held a joint meeting on February 15 with the Electrical Section of the Franklin Institute. Mr. H. Clyde Snook presided. Mr. William Stanley presented a paper on "The Alternating Current in America," which was discussed by Messrs. Pope, Hoadley, Hering, Snook, and Thomas Spencer. There was an attendance of 83 at this meeting.

On March 7 the Philadelphia Section held a meeting conjointly with the Franklin Institute and the American Society of Mechanical Engineers. Mr. Thomas Spencer presided at the meeting, which was attended by 140 members and visitors. The paper of the evening, "Electrification of Main Line Railways," was presented by Mr. W. J. Clark. It was discussed by Messrs. B. F. Wood, Frederick Darlington, Henderson and Klumpp.

PITTSBURG

The Pittsburg Section met on March 12 in the auditorium of the Engineering Society of Western Pennsylvania. The meeting, at which Chairman K. C. Randall presided, was attended by 115 members and visitors. After a discussion of the proposed amendments to the Constitution, a paper on "Some Phases of Modern Switchboard Design and Construction" was presented by Mr. Saul Lavine, and discussed by Messrs. F. D. Egan, C. G. Schluderberg, E. Friedlaender, and C. McL. Moss.

PITTSFIELD

The sixth meeting of the Pittsfield Section was held on February 15 at the Hotel Wendell. Mr. G. Faccioli presided at the meeting, which was attended by 90 members and visitors. Mr. W. S. Andrews of the consulting engineering department of the General Electric Company gave an illustrated lecture on "Phosphorescence and Fluorescence." Mr. Andrews said that the phenomena of light that are independent of sensible heat are known by the general name of luminescence. Under this heading come the transient effect known as fluorescence, and the persistent effect termed phosphorescence. The two are closely akin, perhaps only different phases of the same phenomenon. The only difference is that fluorescent light disappears the instant exciting waves are cut off, whereas phosphorescent objects continue to shine for an appreciable period thereafter. When so-called fluorescent objects are examined in a phosphoroscope, many of them show phosphorescence for perhaps a small fraction of a second. Mr. Andrews exhibited some of the color effects obtained by coloring phosphorescent compound with aniline dies. Various tints are produced by the proper mixing of different amounts of rhodamin and calcium sulphide. Artificially colored phosphorescence has also been adapted to the construction of a light-transforming reflector, by which a considerable amount of red light can be added to the illumination of the mercury arc, thus making it more like ordinary light and more suitable for showing objects in their natural colors. Mr. Andrews demonstrated this by a rhodamin screen placed before a mercury arc. He also demonstrated color effects due to ultra-violet rays, by means of the light of an iron arc. It is known that glass and mica are opaque to ultra-violet waves, and the disappearance of color was shown when the glass plate was placed in front of the iron arc. A plate of selenite, however, did not obliterate the colors. Mr. Andrews' lecture was followed with close attention by his auditors, who were given an opportunity to examine the apparatus.

The seventh meeting of the Pittsfield Section was held at the Hotel Wendell on March 1, with an attendance of 58. Mr. W. C. Smith presided. There were two speakers. Mr. S. H. Blake talked on "Recent Developments in Flame Arc Lamps," giving a brief history of the development of these lamps and supplementing his talk with lantern slides showing the construction of various types. Mr. E. T. Shaw spoke on "Single-Phase Repulsion Induction Motors," outlining the successive stages in the development of this motor and its characteristics at different stages.

PORTLAND, ORE.

The regular meeting of the Portland Section was held on February 20, in the assembly hall of the Electric Building, and attended by 40 members and visitors. Chairman F. D. Weber presided. The Chairman reported on the preparations that had been made for the Pacific Coast meeting to be held in Portland April 16–20, and appointed a committee to take up the matter of securing coöperation between the Portland Section and the other local engineering bodies. Mr. J. B. Knapp, of the United States Forest Service, gave an instructive talk on "Preservative Treatment and Strength of Poles," which called forth considerable discussion.

SAN FRANCISCO

The regular monthly meeting of the San Francisco Section was held on February 23 at 333 Grant Avenue, Mr. H. W. Crozier presiding. One hundred and fifty-eight members and visitors attended the meeting. The members resolved, in view of the report that the United States Government was considering the establishment of a branch Standardizing Laboratory on the Pacific Coast, to direct their efforts toward securing the location of this laboratory in San Francisco. Mr. S. L. Naphtaly of the Great Western Power Company presented a paper on the company's cable crossing San Francisco Bay. With the aid of lantern slides Mr. Naphtaly showed in detail the method of splicing and laying the 11,000-volt, three-phase cable under the Bay. The cable is so designed that it will transmit approximately 5,000 kw. at 11,000 volts. A great deal of interest was taken in the subject, as was manifested by the large attendance. Engineers from the Pacific Telephone and Telegraph Company contributed to the interesting discussion, giving a great many details which they have encountered in the work on their own cable. Previous to the meeting an informal dinner was held at the Old Poodle Dog Restaurant, at which there was an attendance of about twenty members.

SCHENECTADY

The 107th meeting of the Schenectady Section convened in the assembly room of the General Electric Company building No. 2, on February 27, the Section chairman, Mr. E. B. Merriam, presiding. Mr. R. C. Mair of the Power and Mining Department, General Electric Company, briefly abstracted Mr. Moses' paper on isolated plants presented at the Institute meeting in New York on January 12. After summarizing the points brought out in the paper, Mr. Mair remarked that the paper omitted consideration of large industrial plants such as steel, woolen and paper mills and leather factories, where the steam utilized in heating water and which would otherwise be wasted is now sent through low pressure turbines and electricity generated at practically no operating cost. The discussion following was participated in by Messrs. H. R. Summerhayes, Campbell Macmillan, R. D. Mure, E. P. Edwards, S. W. Mauger and C. A. S. Howlett, who called attention to various details of isolated plant practice. Fifty-one Section members were present at this meeting.

The Schenectady Section held its 108th meeting on March 5 in Red Men's Hall, Mr. E. A. Baldwin, junior past chairman, presiding. About 220 members and guests attended. Mr. Baldwin introduced Mr. Ralph D. Mershon, who read an interesting paper entitled, "What Engineers Should Know Concerning the Rudiments of Corporate Finance." Mr. Mershon's paper was discussed by Messrs. H. W. Darling, D. B. Rushmore and J. R. Werth.

SEATTLE

The regular February meeting of the Seattle Section was held February 17 in the assembly hall at the Chamber of Commerce. Mr. J. D. Ross presented a paper entitled "Plant Efficiency," giving in detail a careful analysis of the losses in the Seattle Municipal Light and Power Plant. The all-day efficiencies of every part of the system from the penstock intake at Cedar Falls to the consumers' circuits in Seattle were given in detail. A very interesting discussion followed, participated in by Messrs. Allen, Quinan, Collins, Whitney, Harisberger, Hoskins, Thatcher and others. About eighty members and visitors attended. Chairman Ross announced the appointment of the following committees: executive: J. Harisberger, A. A. Miller, George Cooley; papers: S. C. Lindsay, A. E. Ransom, George H. Moore; members: John R. King, Burton R. Stare and E. A. Loew.

ST. LOUIS

The regular monthly meeting of the St. Louis Section was held on February 14 in the rooms of the Engineers Club. Chairman George W. Lamke presided.

Mr. F. N. Jewett of the Wagner Electric Manufacturing Company, gave a very interesting paper on "Central Station Heating." The media mentioned by the author as most commonly used for conveying heat are air, steam and water. As the paper dealt particularly with the problem from the central station point of view, the steam and hot water systems now in use for utilizing the heat from the engines as a by-product of the manufacture of electricity were described in considerable detail and illustrated with lantern slides.

In the large buildings such as stores, hotels, etc., where the necessity for heating during seven months of the year would require the installation of boilers of considerable capacity, there is a big incentive to install an isolated lighting plant, as the electric current can be considered as a by-product of the heating system. It is to prevent the installation of such isolated plants that makes it desirable for the central station to take care of the heating as well as the lighting load. It has been demonstrated in a number of instances that the installation of such a system in the main business district of a city is a paying investment not only on account of the extra lighting load secured to the central station through the discouragement of the isolated plant, but also on account of the net profit from the sale of heat. The author stated that central station heating systems of this kind had been installed in nearly one hundred and fifty cities of this country.

In the discussion following the paper Mr. Lamke described a type of condensation meter used to measure the amount of heat furnished. The discussion was also participated in by Messrs. Von Maur, Humphrey, Kraeuchi and others. There was a total attendance of forty-three members and guests.

TOLEDO

The Toledo Section met on March 1 at the Toledo Commerce Club. Mr. George E. Kirk, Section chairman, presided. Twenty-seven members and visitors attended.

Mr. John Gilmartin addressed the meeting on "Electrical Measurements," illustrating his points with blackboard sketches. Mr. Gilmartin discussed all of the principles used in the various types of measuring instruments down to the present day, including the chemical, electrostatic and the various types of electromagnetic meters. Different types of voltmeters, watt-hour meters and maximum demand meters were on exhibition. A discussion followed the lecture.

TORONTO

The regular monthly meeting of the Toronto Section was held at the Engineers' Club on February 2.

Mr. F. C. E. Burnett, chief engineer of the Canada Cement Company of Montreal, presented a paper, illustrated by stereopticon views, on " Electricity in the Portland Cement Industry." After briefly reviewing the rapid growth of the cement industry in recent years, and stating that practically all the cement plants in Canada are operated from hydroelectric power, Mr. Burnett gave an account of the motor drive used throughout his company's various mills.

The discussion of the paper was taken part in by Messrs. Mudge, Kemble, Beames, Butchart, Stone, Boyd, Mitchell, Bucke and Mills. Fifty-four members and visitors attended the meeting, which was presided over by Chairman A. L. Mudge.

URBANA

The Urbana Section met at the University of Illinois on February 21, Prof. E. H. Waldo, chairman, presiding. The feature of the evening was an original paper by Dr. C. T. Knipp of the physics department on the " Properties of the Wehnelt Cathode Rays."

Dr. Knipp discussed briefly the discharge of electricity through gases and mentioned the fact that it was easier to study the behavior of electric flow in rarified gases than in solid or liquid conductors. He described how the Wehnelt cathode was constructed and operated and gave the advantages of this cathode over the ordinary form. The lecture was largely experimental, and Dr. Knipp by several complicated and successful experiments demonstrated the behavior of rays from the Wehnelt cathode. He showed that these rays were deflected by both an electric and a magnetic field and derived the simple equations for these deflectors.

Magnetic and electric fields were simultaneously applied so as to produce deflections at right angles to each other and the rays were deflected into the form of a helix. Dr. Knipp pointed out here that the rays tended to follow the direction of the lines of force of the magnetic field. This phenomenon was shown with several forms of apparatus. Dr. Knipp mentioned the possible application of this phenomenon to the measurement of current.

This paper was one of extreme interest and it was unfortunate that the blizzard which prevailed that evening prevented a larger attendance. However, the 40 who braved the drifts and storm felt well repaid for their efforts.

WASHINGTON, D. C.

The February meeting of the Washington Section was held on February 13, at the Telephone Building.

Mr. John H. Finney, Southern manager of the Aluminum Company of America, and a member of the Public Policy Committee of the Institute, delivered an address on " The Work and Purposes of the Public Policy Committee of the A. I. E. E. and its Bearing on Electrical Development." In his remarks the speaker described the work and aims of the Public Policy Committee concerning matters of public importance, referring especially to the appearance of the committee before the National Waterways Commission in Washington in November last. The speaker pointed out the possibilities of amount and value of water power development and the advantage to be gained to the nation through the early development of these resources, saying that engineering was in advance of legislation in the matter, and showing the need of a definite water power policy controlling legislation that would encourage the building and operation of water power plants. A very thorough exposition was made of the present conditions regarding legislation and the remedies that are possible. The speaker read the brief of the Public Policy Committee submitted to the National Waterways Commission and commented freely upon the various engineering conclusions so forcibly expressed therein. At the close of his remarks Mr. Finney showed a number of views of various Southern water power developments.

Following the presentation of the paper there was a discussion participated in by Messrs. W. F. Smith, F. B. Barry, J. H. Hanna and Earl Wheeler of Washington, and Colonel J. A. Laird of St. Louis, who was a visitor.

Chairman Earl Wheeler announced that Mr. H. C. Eddy had been elected Section secretary by the executive committee to fill out the term of Mr. H. B. Stabler, resigned, and that Mr. C. B. Mirick had been elected a member of the executive committee to fill the vacancy caused by the election of Mr. Eddy to the secretaryship. The Section adopted a resolution of regret concerning the resignation of Mr. Stabler and appreciation of his services. Sixty-five members and visitors attended the meeting.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The University of Arkansas Branch held a meeting on February 6, Mr. F. H. Oneal presiding. Mr. Shaw contributed a paper on alternating-current motor control, which was read by Mr. Watkins. Professor Olney presented a paper on loaded telephone circuits, describing the use of the Pupin coil in the New York-Denver line. Professor Olney's paper was discussed by Mr. Oneal, Professor Stelzner and others.

At the meeting on February 20 Professor Briscoe gave a talk on "The Engineering Student and the Curriculum," emphasizing the point that the student whose training was confined to the required technical course would have a very narrow education, and that he can better prepare himself to fulfill the duty he owes to his country socially and as a citizen by devoting considerable time to literary and other courses that will give him a wider outlook. Professor Stelzner read a paper by Mr. H. S. Bagley, now with the Westinghouse Electric and Manufacturing Company, on "Inner Poles on Alternating-Current Machinery."

At the meeting of the University of Arkansas Branch on March 5, which was attended by twenty members and students, Professor W. N. Gladson gave a lecture on "The Power of Arkansas Streams." His paper was interesting and valuable, based as it was on actual survey and calculations made by himself.

ARMOUR INSTITUTE OF TECHNOLOGY

The Armour Institute Branch held a meeting on February 14, at the Boston Oyster House, Chicago, which was attended by forty members, students and visitors. After dinner had been served, Mr. P. G. Downton, '09, addressed the meeting on "The Engineering Application of Storage Batteries." The speaker covered briefly the use of storage batteries in railway, central station, and isolated plant work. The discussion brought out details on any applications in which the members were particularly interested. After the discussion on direct-current regulation, the speaker took up the subject of storage battery regulation of alternating-current loads.

The second February meeting of the Branch was held in Chapin Hall on February 28. The meeting was to have been addressed by Mr. V. Pagliarulo, '12, on "The Electrical Equipment of the West Side Metropolitan Railway," but owing to the small attendance it was resolved to postpone the address to some future meeting.

UNIVERSITY OF CALIFORNIA

The University of California Branch held a meeting on February 7, Chairman J. F. Pollard presiding. Mr. A. V. Guillou read a paper on "Illumination," dealing with the illuminating of house and store to secure the best results.

At the meeting of the Branch on February 20, Mr. A. F. Bridge presented an interesting discussion of the practicability of the application of high-tension direct-current transmission to Pacific Coast hydroelectric installations. The paper was based partly upon Mr. Elwell's paper read before the San Francisco Section and upon certain original thesis work. The advantages and disadvantages of the direct-current system were explained in detail.

On February 27 the meeting of the Branch was attended by seventeen students and visitors. Mr. F. E. Pernot read a paper upon "Wave Motion and Vector Representation of Alternating Currents as applied to Transmission Lines." The calculations used in the discussion were treated in a very clear manner and were further illustrated by several diagrams which aided greatly in explaining many points of interest.

UNIVERSITY OF CINCINNATI

The University of Cincinnati Branch met on February 9, Chairman W. H. Jefferson presiding. The University has erected within the last year three new buildings, gymnasium, engineering building, and power plant. The chairman introduced as the speaker of the evening Mr. Walter A. Franz, the consulting engineer for these new buildings.

Mr. Franz, by means of black board and blue prints, showed very clearly the reasons for making the various installations of machinery and lighting and power circuits as he did. The installation of 2,300-volt a-c. generators in the power plant had caused considerable comment. It was shown that, all things considered, this high voltage was more economical than a three-wire 220-volt d-c. installation would have been. Futhermore, the city service wires could not have been used in case of an emergency with a three-wire 220-volt d-c. system, while with 2,300-volt a-c. this connection with an outside source of supply could readily be accomplished.

The power plant is connected to the various buildings by means of two tunnels, used both for steam pipe lines and electric circuits. This tunnel is approximately 1,500 ft. long, and is 6 ft. 6 in. wide by 7 ft. 6 in. high, inside, the electric conduit being placed in the cement roof with suitable outlets. Therefore there is plenty of room for working within the tunnel, and plenty, also, to allow for future expansion in case of new buildings being erected.

After the lecture the meeting adjourned to investigate the tunnel and power plant. The operation of the various mechanisms for testing the installation were gone into quite thoroughly, especially a device on the governor of one of the two generating units. This device is used to vary the speed of the engine while paralleling the generators. It consists of a small motor, mounted on a spoke of the fly-wheel, which, through a system of gears and levers, increases or decreases the tension on the governor spring. This motor is operated from the switchboard.

COLORADO STATE COLLEGE

The Colorado State Agricultural College Branch held a meeting on January 29, when the subject of thawing out water pipes by electricity was presented by Professor F. A. DeLay.

At the regular meeting of the Branch held on February 12 a talk on the factory testing of electrical machines was given by Mr. Fred J. B. Rankin. Mr. Rankin has had considerable experience in this line of work and his talk was very informative. The recent Institute paper by Mr. Gus A. Maier, on "Methods of Varying the Speed of Alternating-Current Motors," was abstracted and discussed by Mr. A. A. Catlin.

At the meeting of the Branch on February 26 Mr. Pume gave a talk on the methods used by the Brooklyn Edison Company in advertising during the Hudson-Fulton celebration. Mr. Pume was connected with the company at that time and had considerable to do with the decorating. The Branch is planning for an Electric Show in the near future, when the electrical engineering building will be open to visitors, with all the machines running, and everything that can be obtained in the electrical line will be on exhibition.

UNIVERSITY OF COLORADO

The regular meeting of the University of Colorado Branch was held February 7, with Mr. Edwin Yawger of the Westinghouse Machine Company as speaker. Mr. Yawger chose for his subject the Parsons steam turbine and the condenser. He briefly outlined the history of the turbine, the thermodynamics and the general workings of the turbine and condenser, using numerous slides to illustrate his points.

UNIVERSITY OF IOWA

At the meeting of the University of Iowa Branch on January 15, a lecture on "The Hydroelectric Development of the Mississippi River at Keokuk, Iowa," was given by Mr. Hugh L. Cooper, chief engineer of the Mississippi River Power Company. The lecture was of a popular nature, illustrated, and was attended by 300 members and visitors.

The Branch held a meeting on January 29, at which Mr. P. A. Jans talked on "Automatic Telephony."

KANSAS STATE COLLEGE

The Kansas State Agricultural College Branch held a meeting on February 6, when Professor A. A. Potter lectured on the subject "Prime Movers."

UNIVERSITY OF KANSAS

The University of Kansas Branch held a meeting on February 29, which was attended by twenty-five members and students. Mr. J. T. Skinner, manager of the Lawrence Railway and Light Company, spoke on some of the problems that confront managers of public service companies. He told how the minimum rate per month for lighting was fixed, and spoke of the difficulty some consumers had in understanding it. Following Mr. Skinner's talk, Mr. M. H. Hobbs gave a review of current electrical literature, speaking especially of the new Los Angeles Aqueduct development.

KENTUCKY STATE UNIVERSITY

The Kentucky State University Branch held a meeting on February 10, which was attended by twenty-six members and students. The program was made up of the following topics: "Central Station Generation of Power at Mining Centers," V. B. Milligan; "The Composition and Preparation of Electrodes for Luminous Arc Lamps," L. C. Hardesty; and "Automatic Regulation of Direct-Current Machines," H. C. Galloway.

LEHIGH UNIVERSITY

The Lehigh University Branch held a meeting on February 20, which was attended by forty-seven members and students. Mr. A. F. Wotring, '12, read a paper on "Telephony." Mr. Wotring discussed up-to-date practice with especial reference to the loading of lines to balance the increased capacity effect of very long circuits, thus making conversation more distinct. Mr. R. S. Wenner, '12, read a paper on "Selenium," a substance which has the peculiar property of changing its resistance under the influence of light. The paper described the selenium cell and some interesting experiments that can be performed with it. The last paper of the evening was read by Mr. E. A. Wolfe, of the Westinghouse Company, on "Industrial Motors and their Applications." Mr. Wolfe gave a complete description of the various direct and alternating-current motors, telling the particular sphere of each type, illustrating his talk with a number of excellent slides.

UNIVERSITY OF MICHIGAN

The University of Michigan Branch held a meeting on January 16, when Mr.

J. C. Mock, electrical engineer of the Michigan Central Railroad, delivered an address on "Electric Signals on Railroads." Fifty-one attended the meeting.

Mr. Mock went briefly into the history of the development of railway signals, bringing out some of the defects of the different systems and explaining how they have been eliminated. He described some of the systems in use at the present time,—the electro-pneumatic system as used by the Pennsylvania Lines, and the electric motor-operated system. In the latter system the motor is operated by a potash battery of sixteen cells, which with fifty operations per day will last approximately two years. Mr. Mock stated that out of 9,000,000 operations per year reported on one railroad, there were only 235 failures, where the motor-operated system was used.

UNIVERSITY OF MISSOURI

The University of Missouri Branch held a meeting on February 12. A paper on "Lightning Protection" was presented by Messrs. De Vilbiss and Leonard. Mr. De Vilbiss reviewed the history of the study of static electricity. Mr. Leonard discussed the value of overhead grounded wires, and the desirable characteristics of spark gaps, resistances, choke-coils, and insulators, as shown by the experience with some high-tension transmission systems. Messrs. Hancock and O. Bannon presented a review of the work and conclusions of the Lighting Research Committee (London, 1905). Professor Shaw discussed several aspects of the protection of buildings from lightning, citing some of the interesting figures of probable absolute values of current and voltage, as estimated in one of Doctor Steinmetz's papers.

The Branch held a meeting on February 26, which was attended by thirty-four members, students, and visitors. Judge E. W. Hinton addressed the meeting on the subject of "Contracts." He gave an outline of the history of legal contracts, showing why it was necessary for courts to make their rulings on the basis of the meaning of the language in the document rather than on the understanding of the contracting parties, and he indicated the manner of reasoning by which the courts arrive at their conclusions.

UNIVERSITY OF NEBRASKA

The University of Nebraska Branch held its first meeting of the year on February 27. Professor J. D. Hoffman addressed the meeting on "The Elements which Lead to Success in Consulting Engineering." Professor Hoffman discussed the personal characteristics of the individual, the necessary qualifications of the employer, and the duties of a public service corporation servant. Professor George H. Morse then reviewed for the students the By-Laws and general machinery of the Branch organization of the Institute. Twenty-six attended the meeting.

NEW HAMPSHIRE COLLEGE

At the fourth meeting of the New Hampshire College Branch on February 12, Professor Forrest E. Cardullo gave a lecture on "The Man with the Dinner Pail." To illustrate his subject the speaker described the life of the men who worked in the Titusville Iron Company's Works in Pennsylvania as he found it while there as an apprentice. The problems which are met by an apprentice were clearly brought out, showing that his chief problem is that of the study of the men with whom he works.

At the fifth meeting of the Branch on February 26, Professor Charles E. Hewitt gave an illustrated lecture, "A Study of the Hydroelectric Development at Hinsdale, N. H." The speaker began by explaining the difference between partial and complete development and cited cases of each. He then gave a brief history of the development at Hinsdale. The construction of the plant, dam, and transmission lines was then taken up.

N. C. COLLEGE OF A. AND M. ARTS

At the meeting of the North Carolina College of Agricultural and Mechanical Arts Branch held on February 28, the recent Institute paper by Mr. P. R. Moses on "Isolated Plants" was read in abstract by Mr. H. M. Walton and then discussed by the students present.

OHIO NORTHERN UNIVERSITY

The Ohio Northern University Branch organized at a meeting held on February 21, in the Administration Building of the university. The following officers were elected for the year: Executive Committee: Professor D. D. Ewing, chairman, Messrs. L. A. Roberts, Floyd Turner, H. D. Bruhn and J. C. Johnston; Branch Chairman, Mr. T. H. Frankenberry; vice-chairman, Mr. J. D. Zimmerman; secretary, Mr. R. L. White; treasurer, Mr. G. C. Joseph. Twenty members were present.

The first regular meeting of the Ohio Northern University Branch was held on March 7, with Chairman Frankenberry presiding. The by-laws of the Branch were read and accepted. Mr. H. J. Meyer read a paper which appeared in the December PROCEEDINGS, entitled "Methods of Varying the Speed of Alternating-Current Motors," by G. A. Maier. A discussion of the paper by Messrs. A. V. Belding, J. D. Zimmerman and Professor D. D. Ewing, followed. Twenty-four members were present.

OHIO STATE UNIVERSITY

The Ohio State University Branch met on February 29 to hear a paper read by Mr. G. O. Weimer of the physics department on "Dielectric Strength of Materials." This paper was especially interesting because original investigations of this subject had been recently carried out in the laboratory of the university by Mr. Weimer and others. Thirty-four members and visitors attended the meeting.

OKLAHOMA A. AND M. COLLEGE

The Oklahoma Agricultural and Mechanical College Branch held a meeting on February 10 at which four papers were presented. Mr. George R. Woods' paper on "Electricity in Mines" was read by Mr. W. E. Dolde: Mr. A. O. Austin's "The High-Efficiency Suspension Insulator" was read by Mr. William Gaudian. "The Great Falls Power Company," by Mr. M. Gibden, was read by Mr. E. C. Hartshorne, and a paper on "The Cunningham Artificial Transmission Line," by Mr. Cunningham, was read by Mr. F. B. Hann.

OREGON AGRICULTURAL COLLEGE

At the meeting of the Oregon Agricultural College Branch on February 3, Mr. F. E. Ewart talked on "Isolated Plants," and Mr. F. L. Kunderman presented a paper on "Switchboard Design."

UNIVERSITY OF OREGON

At the regular monthly meeting of the University of Oregon Branch on February 13, Mr. J. N. McArthur read a paper entitled "The Mixing and Placing of Concrete." Mr. McArthur explained the theory of the concrete mixture and emphasized the necessity of being guided by theoretical considerations in practical work. Reference was made to the construction of a large dam in which the concrete was mixed on the dam and sluiced into place, thus effecting a considerable saving in labor.

Mr. Reid then made some insulation tests with a 10,000-volt testing transformer recently purchased for the department of electrical engineering. The subject of insulation was discussed at some length by those present.

PURDUE UNIVERSITY

At a meeting of the Purdue Branch held February 8, Professor C. H. Beckett was the speaker. His subject was "Corporation Law and Bookkeeping."

The method of organization of an insurance company and the differences in the methods of subdividing accounts of different types of corporations were described and illustrated by specific examples. After discussing certain fundamental principles of bookkeeping the speaker took up the comparison of the balance sheets of such corporations as railways, banks and insurance companies, using as illustrations balance sheets from the sources mentioned. Professor Beckett spoke at some length on stock watering, the methods of concealing such transactions in the balance sheets of the company, and the methods employed by accountants in detecting them. Sixty-five members and visitors were present at the meeting.

The meeting of the Purdue Branch of the A. I. E. E. on March 5 was devoted to a discussion of recent improvements in gas and electric illumination. Various phases of the subject were discussed by five seniors, Messrs. Royer, Mullen, Klippel, Harbaugh and McKinzie, who by reason of special work were well qualified to discuss illuminants.

Mr. R. E. Royer gave a review of modern gas illumination. He pointed out at the start that gas lighting has by no means been replaced by electric lighting, the two systems being at present lusty rivals, with the advantage first on one side, then on the other. The old style open " fish-tail " flame, however, is rapidly disappearing because of the greater efficiency of the Welsbach incandescent mantle. This mantle is a woven fabric impregnated with the oxides of certain rare metals, and its durability depends largely on the material of the original fabric. The best material which has been found is an artificial cellulose. The mantle loses its brilliancy only slowly—five or ten per cent in 8,000 hours. The inverted Welsbach mantle is much more efficient than the upright one, but there were peculiar problems, such as good air supply, which had to be solved before a satisfactory mantle was obtained.

Illuminating gas varies greatly in composition according to its source or mode of manufacture; it always contains constituents which give no light, but much heat, on burning. In the Welsbach burner the heat value is much more important than the lighting value of the gas, hence the old legal standards should be changed to take account of that fact.

The " gas arc " is a cluster of incandescent mantles surrounded by a globe; it looks much like an electric arc lamp, hence the name. Gas arcs are usually provided with an automatic lighter, either a small pilot gas burner or an electrical device.

Mr. H. Mullen took up the electrical side of the illumination question by discussing the new tungsten incandescent lamp. He gave a brief history of the manufacture, starting with the old squirted filament lamp which had so many defects. There were may difficulties in the process, but as perfected it consisted in squirting a paste containing the pure metal through holes, which for low-wattage lamps were about one-thousandth of an inch in diameter, in a diamond. The dies were very expensive and did not last long. The filament, after partial fusion, was fastened to a spider in the lamp. The rigid type of support added to the inherent fragility of the filament. The new drawn-wire filament is manufactured by a secret process, but part of its success depends on the flexible style of support, the filament being merely wrapped onto the spider. It is much more resistant to shock than the old lamp, and has a life on the average of 1,000 hours, as against 500 for a carbon lamp. Other advantages over the carbon lamp are its much smaller power consumption and its smaller sensibility to variations in voltage. It can be made easily in units as large as 500 c-p. and for this reason is being largely used in place of small arc lamps for street lighting.

Mr. W. P. Klippel gave some interesting comparisons of the costs of gas and electric lighting. He stated that for the usual conditions the incandescent gas mantle is cheaper than any electric light. It was pointed out, however, that there are conditions which may reverse the conclusion for special cases.

An interesting branch of the subject, the power cost question, was discussed by Mr. P. B. Harbaugh. He pointed out that there are certain definite factors which should be considered in fixing the cost of power to a consumer. The individual consumer must be considered, for one rate to all kinds of consumers works injustice to the company. The station has to be equipped to furnish the maximum power which may be demanded, and the company can afford to receive less for current which is steady but rather low than for current which may rise to a very high point for a short time. Other things which the company must figure into the cost are taxes on property, interest on investment, labor, maintenance, replacing obsolete or worn-out machinery, and fuel or water power. Power may be paid for by the customer at a "flat rate." depending on his maximum consumption, or on a "meter-rate" depending only on the total amount of energy delivered. Either arrangement is likely to be inequitable either to company or consumer under certain conditions.

Mr. L. H. McKinzie discussed the large number of street lighting systems now in use. Of the desirabilities in a street light he mentioned steadiness of the light, sufficient brilliancy, softness of shadows and protection of the eye from the glare. The impregnated carbon flaming-arc lamps are a recent development; they give an intense yellow light. The metallic electrode arc is also important; its light may be made almost a pure white. The tungsten incandescent lamp is coming to be used largely for ornamental street lighting and is very efficient.

Professor Topping added a few words on the history of street lighting; it was originally a police regulation, designed for safety from thieves, and gradually developed through torches, lanterns, and open gas lights to the very efficient inverted Welsbach burner or the tungsten lamp. The inverted Welsbach is being very successfully used in Europe with high gas pressures, and is partly displacing electricity there. There was an attendance of ninety at this meeting.

RENSSELAER POLYTECHNIC INSTITUTE

The regular monthly meeting of the Rensselaer Polytechnic Institute Branch was held on February 7, and was attended by thirty-three members and visitors. Mr. W. J. Williams read a paper on "Electric Energy," with especial reference to the importance of the time element in the solution of electric energy problems. The discussion of this paper was followed by an exhibition of ozonators. The theory, construction and operation of these devices was explained by Dr. W. L. Robb.

At the meeting of the Branch on March 6, Mr. E. D. N. Schulte read a paper on "The Application of Electricity to Automobiles." Mr. Schulte described the different systems of ignition most generally used at the present time and explained the advantages and disadvantages of each. He then described the principal methods used in lighting automobiles by electricity, and ended his paper with a few remarks on electrically-driven vehicles. Forty-two were present.

ROSE POLYTECHNIC INSTITUTE

The regular meeting of the Rose Polytechnic Institute Branch, held February 16, was devoted to the subject "Alternating-Current Rectifiers," which was presented by Mr. Jerry H. Service, Jr., and Mr. William R. Bell, of the senior class, who had collected data and prepared diagrams of the various rectifiers in use. The rectifiers especially studied were the mercury arc rectifier, one of this type being exhibited, Pollak's aluminum valve rectifier, Murphy rectifier, Wagner alternating-current rectifier, and a small self-starting single-phase synchronous motor commutator rectifier designed and built under the direction of Professor Knipmeyer, which was demonstrated by Professor Wischmeyer. Schematic diagrams of all these rectifiers were drawn on the blackboard and the theory and efficiency discussed. Professor Knipmeyer closed the meeting by giving a general review of the whole field of alternating-current rectifiers as used under different conditions and for various purposes.

STANFORD UNIVERSITY

The Stanford University Branch held a meeting on February 8 which was attended by 26 members and students. A paper on "High-Tension Insulators" was read by R. L. Robinson, '12, and a discussion followed. The Stanford Branch has decided upon a new plan of cutting the number of meetings in half, and endeavoring to obtain for them prominent outside men to speak, instead of having so many student speakers.

SYRACUSE UNIVERSITY

The regular monthly meeting of the Syracuse University Branch was held on February 29, when Mr. H. S. Blakeslee, electrical engineer for the City of Syracuse, gave a talk on the testing of electric meters, paying particular attention to the testing of meters in service, the use of phantom loads and of some means of varying the phase relations in order to test the meters at various power factors. The lecture was illustrated with lantern slides.

UNIVERSITY OF VIRGINIA

The first meeting of the University of Virginia Branch was held on February 26. Professor Walter S. Rodman, head of the department of electrical engineering, presided. Professor Rodman explained the purposes of the organization, reading from the Institute By-Laws relating to Branches. Officers were then elected, as follows: Chairman, Professor W. S. Rodman, secretary, Mr. Albert F. Edel; executive committee, these two officers together with Mr. James C. Lamb.

Professor Rodman read Mr. George I. Rhodes' recent Institute paper entitled, "A Method of Studying Power Costs with Reference to the Load Curve and Overload Economies." A short discussion brought out many instructive features.

WORCESTER POLYTECHNIC INSTITUTE

The meeting of the Worcester Polytechnic Branch on February 9 was addressed by Mr. Albert H. Armstrong, W. P. I. '91, on "Heavy Electric Railroading."

Mr. Armstrong, who is assistant engineer of the Railway and Traction Department of the General Electric Company, confined his remarks to the types of electric locomotive made by his company, namely, the direct-current types and the polyphase alternating-current systems, mentioning only briefly the single-phase system.

The lecture was a straightforward description of the problems, and their solution, encountered in the modern electrification of steam roads and especially freight service on the trunk lines. The capacity and limitations of the steam locomotive were first carefully considered and then the ability of the electric type to overcome these limitations was clearly brought out both by calculation and examples of typical installations.

The numerous questions asked at the close of the lecture by many of the one hundred members and friends who were present showed a keen interest in the subject so well presented by Mr. Armstrong.

Mr Howard F. Fritch ,'10, of the Bay State Street Railway Company, addressed the Branch at its last regular meeting, on March 8, upon the subject "The Working Time Tables of an Electric Railway."

Mr. Fritch gave a clear and interesting talk, showing the various steps that are necessary in making up schedules that will be suitable to the riding public and also to the company itself, as well as being convenient for the men who operate the cars. These three factors and their influence upon the schedules were very carefully considered, giving those **not** acquainted with the methods an entirely new vision of the principles upon which street cars operate.

A number of lantern slides and run sheets contributed to the interest by bringing out considerable discussion at the close of the lecture. There was an attendance of fifty at the meeting.

Personal

Mr. Irving W. Phillips has been transferred from the Boston office to the Keokuk, Iowa, office of the Stone and Webster Engineering Corporation.

Mr. Alfred Müllhaupt, Jr., electrical engineer, formerly of St. Marys, Pa., has accepted a position with the Corliss Carbon Company, Bradford, Pa.

Mr. H. W. Turner, who for the past three and one-half years has been connected with the European office of the Sterling Varnish Company, has now established himself as a winding and insulation specialist, with an office at Nutsford Vale Works, Manchester, England.

Mr. Stanley R. Edwards has rejoined the editorial staff of *Telephony* as technical editor, succeeding Mr. F. H. Reed, resigned. Mr. Edwards had been formerly assistant editor of that paper for a period of about two years, until the connection was terminated by his illness in October, 1910.

Mr. Herman F. Weber has resigned his position as mechanical engineer with the Electric Bond and Share Company, to associate himself with Mr. James Gamble, under the firm name Gamble and Weber, 15 William St., New York. The firm will undertake the financing construction and operation of public utilities for water, gas and electric light and power.

Mr. Franklin H. Reed has severed his editorial connection with *Telephony*, and joined the organization of the Traffic Service Bureau, of Chicago and Washington. Mr. Reed's time will now be largely devoted to the development of The Traffic Service Bureau's paper, *Public Service Regulation*, the official journal of the National Association of Railway Commissioners.

Mr. Charles M. Kirkpatrick, of the Detail and Supply Department of the New York office of the Westinghouse Electric and Manufacturing Company, was married on Wednesday evening, February 28, to Miss Florence Good, daughter of Dr. and Mrs. S. L. Good, at their home in East Orange, New Jersey. Mr. and Mrs. Kirkpatrick will make their home in East Orange after their return from an extended bridal tour.

Mr. James Rowland Bibbins, of Chicago, has recently established offices in the Hewes Building, San Francisco, for Bion J. Arnold, consulting engineer, of Chicago, as engineer in charge of a comprehensive investigation of traction necessities and development in San Francisco, upon which Mr. Arnold has been commissioned by the Board of Supervisors to report in the near future. Mr. Bibbins comes to this work directly from similar technical investigations at Providence, Rhode Island, and Pittsburgh, Pa. His home office continues 1,000 Borland Building, Chicago.

Obituary

Mr. Junzo Itoh, of Takata and Company, died on January 14, 1912, in Tokio, Japan, of typhoid fever.

Mr. Itoh was born March 23, 1881, in Kaitogori, Aichi, Japan, and was graduated from the Technical College of the Imperial University, Tokio, in 1904. He was employed as assistant electrical engineer with the Tokio Electric Railway Company, and as electrical engineer with the Municipal Electric Railway Department of Osaka, until 1907, when he became associated with Takata and Company, of Tokio. On June 21, 1907, Mr. Itoh was elected an Associate of the Institute. Early in 1911 he came to the New York office of the company, and recently returned to Tokio.

Mr. Edwin H. Bennett, vice-president and general manager of the Singer Sewing Machine Company, died on February 21, 1912, in Berlin, Germany, of pneumonia, after an illness of five days. He was abroad in the interests of the company, on a tour of inspection of Singer factories in Scotland, Germany and Russia, and contracted a severe cold while inspecting the plant in Glasgow. Mr. Bennett made his home in Bayonne, N. J., and maintained an office at the Singer works in Elizabethport, N. J.

Mr. Bennett was 45 years old, and was the son of the late William H. Bennett, for several years treasurer of the Singer Sewing Machine Company. He received his technical education at Cornell University, and was first employed by an electric light plant in Rochester, N.Y. He was elected an Associate of the A.I.E.E. on June 20, 1894. After he became connected with the Singer Sewing Machine Company, Mr. Bennett's ability as an organizer and successful manager soon gained recognition, and he steadily worked his way up in the organization until he attained the important positions of first vice-president and general manager. Of late years, although he lived in Bayonne, most of his work has been in foreign fields, and the marked success of the Singer Company in the European field is attributed to his energetic efforts. He had crossed the Atlantic Ocean fifty-seven times.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Anuario Técnico é Industrial de España. 1911. Madrid, 1911. (Purchase.)

Application of Hyperbolic Functions to Electrical Engineering Problems. By A. E. Kennelly. London, Hodder & Stoughton, 1912. (Gift of University of London Press.) Price 6 shillings net.

Prof. P. G. Tait wrote, more than fifty years ago, in the preface to his "Treatise on Quaternions" as follows: "It must always be remembered that Cartesian methods are mere peculiar cases of Quaternions where most of the distinctive features have disappeared. Nothing is ever lost, though much is generally gained, by employing Quaternions in preference to ordinary methods. In fact, even when Quaternions degrade to scalars, they give the solution of the most general statement of the problem they are applied to, quite independent of any limitations as to choice of particular co-ordinate axes."

The truth of this statement is strikingly illustrated in the above named work of Prof. Kennelly, covering the scope and purport of five lectures given for the University of London, at the Institution of Electrical Engineers, in May and June, 1911. Prof. Kennelly applies the method of complex variables not only to alternating current phenomena, where it has become the standard method, but also to continuous current line calculations, and derives simple expressions for the various characteristics of continuous current lines of uniform resistance and leakance in the steady state, and for equivalent circuits of conducting lines in the same state. The last five chapters are devoted to various applications of hyperbolic functions to alternating current phenomena in simple uniform lines and power transmission lines, and to wire telephony and telegraphy. Two chapters are devoted to the explanation of the principles of hyperbolic trigonometry, and the use of complex quantities. Notwithstanding its seemingly abstruse subject, the book is comparatively very easy to read, and can be mastered without particular difficulties by anybody with a knowledge of the elements of calculus.

Calcul et Construction des Alternateurs Mono-et Polyphasés. By Henri

Birven. Paris, 1911. (Gift of Gauther-Villars.)·

Carnegie Institution of Washington. Department of Terrestrial Magnetism. Annual Report of the Director. 1911, n.p.n.d. (Gift of Carnegie Institution of Washington.)

Centrifugal Pump, Turbines and Water Motors: including theory and practice of hydraulics. Ed. 5 By Chas. H. Innes. London, 1909. (Purchase.)

Cours Municipal d'Electricité Industrielle. Vols. 1–2. By L. Barbillion. Paris, 1907, 1911. (Purchase.)

Die elektrochemischen Verfahren der chemischen Gross-Industrie. By Jean Billiter. Halle A. S., 1909, 1911. (Purchase.)

Das Gewitter. Ed. 2. By Albert Gockel. Köln, 1905. (Purchase.)

Glossary of Technical Terms used in Architecture and the Building Trades. By G. J. Burns. London-New York. 1895. (Purchase.)

Holy Bible, New York, 1910. (Purchase.)

Hydraulic Power and Hydraulic Machinery. Ed. 3. By Henry Robinson. London, 1910. (Purchase.)

Incorporated Municipal Electrical Association. Proceedings. 1903–1911. London, 1903–11. (Purchase.)

Matières Premières de la Fabrication du Caoutchouc de la Gutta Percha et des Industries Connexes. By R. Marzahn. Paris, 1911. (Purchase.)

Mechanismes de L'electricite et de L'Univers. By J. C. F. de la Perriere. Tome I. Paris, 1756. (Gift of W. D. Weaver Fund.)

Michigan Electric Association. Annual Convention, 8th, Minnesota, 1911. Detroit, 1911. (Gift of National Electric Light Asso., Michigan Section.)

National Waterways Commission. Hearings on the Development and Control of Water Power, Nov. 21–24, 1911. (Government Document No. 274.) Washington, 1912. (Gift of National Waterways Commission.)

Neuere Turbinenanlagen. By Wilhelm Wagenbach. Berlin, 1905. (Purchase.)

New England Water Works Association. Journal. Vol. 1, No. 4, June, 1887; Vol. 2, No. 2, Dec., 1887; Vol. 4, No. 1, Sept. 1889; Vol. 7, No. 1, Sept. 1892; Vol. 15, No. 6, Dec., 1901. Boston, 1887, 1889, 1892, 1901. (Gift of Engineering News.)

New York (State) Department of Labor. Annual Report of the Commission. 11th, 1911. Albany, 1912. (Gift of New York State Department of Labor.)

Nouvelle Physique Celeste et Terrestre, a la portee de tout le Monde. By J. C. F. de la Perriere. Tome 2. Paris, 1766. (Gift of W. D. Weaver Fund.)

Outlines of Applied Optics. By P. G. Nutting. Philadelphia, P. Blakiston's Son & Co., 1912. (Gift of Publishers.) Price, $2.00 net.

This work deals with optical instruments and optical measurements from a standpoint of sensibility and precision. The first three chapters treat of instruments for forming images; the remaining chapters special instruments for analyzing light determining the properties of the materials. The keynote throughout is the question of securing the best possible results in optical work. (Extract from the preface.)

This extremely interesting work covers a field which practically has been uncovered up to the present time. Bringing together in one compact volume much material contained in the well-known works on optics, together with much new material not found in any of them. An interesting feature of the work is the bibliography appended to each chapter. These bibliographies when combined make a very fine working and complete bibliography of the subject of optical engineering. W. P. C.

Projektierung und Betrieb von elektrischen Beleuchtungs und Kraftübertragungs anlagen. By F. Hoppe. Karlsruhe, 1907. (Purchase.)

Rhode Island. Traction Improvement and Development within the Providence District. Report on the

Joint Committee on Railroad Franchises. By B. J. Arnold. Providence, June, 1911. (Gift of author.)

Rugby Engineering Society. Proceedings. Vol. 8, Rugby, 1911. (Exchange.)

Statistik der Kleinbahnen im Deutschen Reich fur das Jahr, 1910. Berlin, 1912. (Exchange.)

Telegraphen und Fernsprech-Technik in Einzeldarstellungen. Vols. 1–10. By Th. Karrass. Braunschweig, 1906–1911. (Purchase.)

Telephony. A comprehensive and detailed exposition of the theory and practice of the telephone art. By S. G. McMeen and K. B. Miller. Chicago, American School of Correspondence, 1912. (Gift of Publishers.)

The rapid development of the correspondence method of teaching has made it possible to publish many valuable handbooks which otherwise would be commercially unprofitable. The present work by two members of the Institute is a good example of this. It is largely a single volume made up from the "Cyclopaedia of Telephony and Telegraphy" in so far as the latter work relates to the telephone, and is the most extensive presentation of the subject since Mr. Miller's "American Telephone Practice." W.P.C.

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——Bull. No. 4901—A. C. switchboard panels with oil switches on panel. 42 pp.

——Bull. No. 4917—Direct current exciter panels. 8 pp.

——Bull. No. 4918. Direct current switchboards; double polarity, 125, 250, 600 volts. 14 pp.

——Bull. No. 4919—Small plant direct current switchboards. 3 pp.

——Bull. No. 4920—G. E. 203A Railway motors. 16 pp.

——Bull. No. 4924—Thomson prepayment watthour meters for direct and alternating current. 6 pp.

Standard Plunger Elevator Co. New York. Hydraulic passenger and freight elevators. 20 pp.

Sprague Electric Co., New York. Electric fans. 40 pp.

Westinghouse Electric Mfg. Co., East Pittsburgh, Pa. Printometers for use with watthour meters. 10 pp.

Wirt Electric Specialty Co., Germantown, Pa. The Dim-a-Lite lamp. 16 pp.

——Insulating joints for electric fixtures. 12 pp.

——Di-El-Ite resistance units. 12 pp.

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OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL.

DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER. (Term expires July 31, 1912.) **SECRETARY.**

GEORGE A. HAMILTON.

F. L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD,1903-4.
JOHN WILLIAM LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH W. POPE,
3 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

STANDING COMMITTEES.

Revised to April 1, 1912.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
F. L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York.
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
JOHN PRICE JACKSON, State College, Pa.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, Brooklyn.
PERCY HOLBROOK THOMAS, New York.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE.

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

STANDARDS COMMITTEE.

ARTHUR E. KENNELLY, Chairman,
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Secretary,
Harvard University, Cambridge, Mass.
FREDERICK BEDELL, Ithaca, N. Y.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Perth Amboy, N. J.
BENJAMIN G. LAMME, Pittsburgh, Pa.
WILBUR L. MERRILL, Schenectady, N. Y.
HAROLD PENDER, Boston, Mass.
WILLIAM H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburgh, Pa.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
J. FRANKLIN STEVENS, Philadelphia, Pa.

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
CLIFTON V. EDWARDS, New York.
FRED S. HUNTING, Fort Wayne, Ind.
ADDAMS S. McALLISTER, New York.

SPECIAL COMMITTEES.

Revised to April 1, 1912.

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman,
165 Broadway, New York.
EDWIN BRITTON KATTE, Vice-Chairman,
New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

JOHN PRICE JACKSON, Chairman,
State College, Pa.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman,
General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, Brooklyn, N. Y.
PERCY HOLBROOK THOMAS, New York.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman,
120 W. Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill.
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman,
Allis-Chalmers Co., Milwaukee, Wis.
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York.
BARTON ROY SHOVER, Youngstown, Ohio.
ROBERT BELDEN TREAT, Ampere, N. J.
R TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE.

BANCROFT GHERARDI, Chairman,
15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman,
360 Pearl Street, Brooklyn, N. Y.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
CLYDE D. GRAY, New York.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa.

SPECIAL COMMITTEES.—Continued.

Revised to April 1, 1912.

PUBLIC POLICY COMMITTEE.

JOHN J. CARTY, Chairman,
15 Dey St., New York.
HAROLD W. BUCK, New York.
JOHN H. FINNEY, Washington, D. C.
PAUL N. NUNN, Provo, Utah.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

ADDITIONAL GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman,
2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.

MEMBERSHIP COMMITTEE.

CHARLES E. SCRIBNER, Chairman,
463 West Street, New York.
S. B. CHARTERS, San Francisco, Cal.
HENRY FLOY, New York.
GEORGE W. LAMKE, St. Louis, Mo.
A. A. MILLER, Seattle, Wash.
N. J. NEALL, Boston, Mass.
K. C. RANDALL, Pittsburgh, Pa.
DAVID B. RUSHMORE, Schenectady, N. Y.
A. M. SCHOEN, Atlanta, Ga.
H. CLYDE SNOOK, Philadelphia, Pa.
H. B. STABLER, Baltimore, Md.
J. G. WRAY, Chicago, Ill.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman,
52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J

ELECTROPHYSICS COMMITTEE

EDWARD B. ROSA, Chairman,
Bureau of Standards, Washington, D. C.
EDWARD P. HYDE, Cleveland, O.
MALCOLM MACLAREN, Princeton, N. J.
EDWARD L. NICHOLS, Ithaca, N. Y.
HAROLD PENDER, Boston, Mass.
MICHAEL I. PUPIN, New York.
HARRIS J. RYAN, Stanford University, Cal.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
JOHN B. WHITEHEAD, Baltimore, Md.
FRANK A. WOLFF, Washington, D. C.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman,
29 West 39th St., New York
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

INDEXING TRANSACTIONS COMMITTEE

GEORGE IRVING RHODES, Chairman,
600 West 59th Street, New Yor
MORTON GITHENS LLOYD, Chicago, Ill

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President.
90 West St., New Yor
ARTHUR E. KENNELLY, Secretary,
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Cambridge, Mass.
LOUIS BELL, Boston, Mass.
JOHN J. CARTY, New York.
GANO DUNN (ex-officio), New York.
CARL HERING, Philadelphia, Pa.
JOHN W. HOWELL, Newark, N. J.
JOHN W. LIEB, Jr., New York.
RALPH D. MERSHON, New York.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
SAMUEL W. STRATTON, Washington, D. C.

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.

FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.
W. D. WEAVER, New York.

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP PRICE BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913.

COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y.

Term expires July 31, 1912.

WILLIAM S. BARSTOW, New York.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.

LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, Brooklyn, N. Y.

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.

GANO DUNN, President, New York.
F. L. HUTCHINSON, Secretary.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

Revised to April 1, 1912.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

LOUIS A. FERGUSON, Chicago, Ill.
LEWIS BUCKLEY STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.
GANO DUNN, New York.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

WALTER S. RUGG, New York.
HOWEL H. BARNES, JR., New York.
GANO DUNN, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, New Haven, Conn.
SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.
ELIHU THOMSON, Swampscott, Mass.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

EDWARD B. ROSA, Washington, D. C.
JOHN B. WHITEHEAD, Baltimore, Md.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

JOHN J. CARTY, New York.
CALVERT TOWNLEY, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE, G. P. O., Perth, Australia.
HORACE FIELD PARSHALL, Salisbury House, London Wall, E. C., London.
L.A. HERDT, McGill University, Montreal Que.
WILLIAM G. T. GOODMAN, Adelaide, South Australia.
ROBERT JULIAN SCOTT, Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.
CLARE F. BEAMES, Bangalore, Mysore Province, India.

LIST OF SECTIONS.

Revised to April 1, 1912.

Name and when Organized.		Chairman.	Secretary.
Atlanta	Jan. 19, '04	A. M. Schoen.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston	Feb. 13, '03	William L. Hooper	G. A. Rodenbaeck, 84 State St., Boston, Mass.
Chicago	1893	J. G. Wray.	
Cleveland	Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor	Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne	Aug. 14, '08	E. A. Wagner.	A. B. Morrison, 817 Nelson Street, Ft. Wayne, Ind.
Indianapolis-Lafayette	Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles	May 19, '08	O. H. Ensign.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Madison	Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Lynn	Aug. 22, '11	E. E. Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass.
Mexico	Dec. 13, '07	W. H. Fiske.	H. S. Foley, Apartado 124 Bis., Mexico, D. F.
Milwaukee	Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	Chas. L. Pillsbury.	Leo H. Cooper, 805 Metropolitan Life Bldg., Minneapolis, Minn.
Philadelphia	Feb. 18, '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg	Oct. 13, '02	K. C. Randall	E. L. Farrar, G. E. Co., Oliver Bldg., Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore	May 18, '09	F. D. Weber.	H. R. Wakeman, 604 Electric Building, Portland, Ore.
San Francisco	Dec. 23, '04	S. B. Charters.	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady	Jan 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	J. D. Ross.	M. T. Crawford, Seattle-Tacoma Power Co., Seattle, Wash.
St. Louis	Jan. 14, '03	George W. Lamke.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo
Toledo	June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto	Sept. 30, '03	A. L. Mudge.	Valentine Boyd, 212 King St., West, Toronto, Ont.
Urbana	Nov. 25, '02	E. H. Waldo.	F. G. Willson, University of Illinois, Urbana, Ill.
Vancouver	Aug. 22, '11	F. D. Nims	E. M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D. C.	Apr. 9, '03	Earl Wheeler.	H. C. Eddy, Interstate Commerce Commission, Washington, D. C.

Total, 28.

LIST OF BRANCHES.

Revised to April 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	C. E. Greene.	M. L. Johnson, College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Hulse, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	L. H. Roller.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
California, Univ. of..Feb. 9, '12	J. F. Pollard.	B.D.Dexter,1725 Euclid Ave.,Berkeley Cal.
Case School, Cleveland Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	W. H. Jefferson.	Oscar Plueddemann, 3133 Hackberry Street, Cincinnati, O.
Colorado State Agricultural College.......Feb. 11, '10	D. E. Byerley.	A. A. Catlin, 626 So. Meldrum St., Fort Collins, Colo.
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	F. A. Fish.	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	L. J. Kieser.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	B. F. Hillebrandt	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of................Oct. 14, '10	W. H. Jaegle.	J. H. Gaiser, 341 Harrison Ave., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa
Lewis Institute.......Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	Benjamin Haskell	John E. Ash, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, 432 Thompson St., Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	J. Glen Luther.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	E. P. Speer.	W. H. Graham, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
Ohio Northern Univ.Feb. 9, '12	T.H.Frankenberry	R. L. White, 310 Ream St., Ada, Ohio.
Ohio State Univ......Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.....Oct. 13, '11	W. E. Dolde.	H. P. Cook, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.
Oregon State Agr. Col.Mar. 24, '08	H. Belknap.	W. R. Varner, Oregon St. Agric. College, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02		
Purdue Univ.........Jan 26, '03	C. F. Harding.	A. L. Topping, Purdue University, Lafayette, Ind.
Rensselaer Poly. Inst.Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Rose Polytechnic Inst.Nov. 10, '11	Jerry H. Service, Jr.	David W. Jones, 911 North 8th Street, Terre Haute, Ind.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.......Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.......Feb. 14, '08	J. A. Correll	N. H. Brown, University of Texas, Austin, Tex.
Throop Poly. Inst....Oct. 14, '10	Frank C. Miller.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal.
Vermont, Univ. of... Nov. 11, '10	Walter L. Upson.	O. Krupp, 65 North Bend St., Burlington, Vt.
Virginia, Univ. of...Feb. 9, '12	Walter S. Rodman	Albert F. Edel, P. O. Box 115, University, Va.
Wash., State Coll. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Irwin L. Cheney.	P. S. Stevens, Washington University, St. Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.
Yale University......Oct. 13, '11	B. C. Beck.	J. H. Shallenberger, 166 Vanderbilt-Scientific, New Haven, Conn.

Total, 42

PROCEEDINGS
OF THE
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OF
Electrical Engineers.

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THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol XXXI **May, 1912** No. 5

Annual Meeting of A. I. E. E. in New York, May 21, 1912

The Annual Meeting of the American Institute of Electrical Engineers will be held in the Auditorium of the Engineers Building, 33 West 39th Street, New York, on Tuesday, May 21, 1912, at 8.15 p.m. The Board of Directors will present its report for the fiscal year ending April 30, 1912. The report will include a detailed statement of the financial status of the Institute, and will give a summary of the work accomplished by the standing and special committees during the year.

At this meeting the reports of the Committee of Tellers on the election of officers for the ensuing administrative year and on the ballots upon the Constitutional amendments will be presented.

As a token of the friendly relations existing between the American Institute of Electrical Engineers and the Associazione Elettrotecnica Italiana and as an expression of appreciation of the many courtesies and hospitalities received by the President and Members of the American Institute of Electrical Engineers at the International Electrical Congress, held in Turin in September last, a bronze bust of Joseph Henry will be presented by the Institute to the Associazione Elettrotecnica Italiana. Addresses will be delivered by Dr. Michael I. Pupin on "Henry as a Scientist" and by Mr. John C. Barclay on "Henry as the Inventor of the Telegraph." A representative delegated by the Associazione Elettrotecnica Italiana will respond in behalf of his society.

Schenectady Meeting, May 17, 1912

The two hundred and seventy-third meeting of the American Institute of Electrical Engineers will be held at Schenectady, N. Y. under the auspices of the Schenectady Section, on May 17, 1912. Technical sessions have been arranged for the morning and part of the evening, and the afternoon and the remainder of the evening will be devoted to various kinds of entertainment.

The official headquarters of the Institute during the meeting will be at the Mohawk Golf Club and the technical sessions will be held in the convention hall.

The morning session will convene at 9 o'clock and the following papers will be presented:

1. *Compression Chamber Lightning Arrester and the Protection of Distribution Circuits*, by E. E. F. Creighton and F. R. Shavor.
2. *Multi-Recorder for Lightning Phenomena and Switching*, by E. E. F. Creighton, H. E. Nichols and P. E. Hosegood.
3. *Studies of Protection and Protective Apparatus for Electric Railways*, by E. E. F. Creighton, F. R. Shavor and R. P. Clark.
4. *Ozone: Its Properties and Its Commercial Production*, by M. W. Franklin.
5. *Propagation of Impulses on a Transmission Line*, by J. H. Cunningham and C. M. Davis.

6. *Frequency*, by D. B. Rushmore.
7. *Some Mechanical Considerations of Transmission Systems*, by T. A. Worcester.
8. *Electrical Characteristics of Suspension Insulators*, by F. W. Peek, Jr.

Following the morning session, a buffet luncheon will be served at the Mohawk Golf Club for those attending the meeting.

The afternoon will be devoted to entertainment and demonstrations. Arrangements are being perfected for events in golfing, boating, motoring and other sports through the courtesy of the Mohawk Golf Club and the Schenectady Boat Club. Officials of the American Locomotive Works and the General Electric Company have also extended the privilege of inspecting the local plants of these two companies to visiting members. In addition, there will be demonstrations of several new types of electric railway cars.

The evening session will convene at 8 o'clock and the following papers will be presented:

9. *Some Impressions of the Electric Traction Situation in Europe*, by C. E. Eveleth.
10. *Freight Train Tests on an Electric Interurban Railway*, by S. T. Dodd.

All of these ten papers, with the exception of No. 6, will be found printed in this issue of the PROCEEDINGS

Immediately after the technical session there is to be an informal smoker, which will give opportunity for those attending to meet and discuss matters of interest to all.

It has not been possible to obtain special transportation rates for this meeting. Members should, therefore, consult their local ticket agents regarding routes and rates. It is suggested that parlor and sleeping car accommodations be engaged in advance in both directions.

As heretofore, each member should arrange for his own hotel accommodations. Correspondence regarding reservations should in all cases be directed to the hotel management.

Hotel	Guest capacity	Proprietor	Plan	Rates per day
Crown	100	James Clair	European	$1.00 up
Edison	150	Edwin Clute	American	2.50 up
Mohawk & Baths	200	Woods and Meehan	European	1.00 up
New Vendome	100	W. J. Gleason	American	2.50 up

The registration headquarters will be immediately opposite the main entrance to the Mohawk Golf Club. Each member and guest should register immediately upon arriving.

Boston Convention Headquarters

Announcement has been made by Mr. C. L. Edgar, chairman of the Convention Committee, and Mr. L. D. Gibbs, chairman of the Sub-committee on Hotel Arrangements for the Boston Convention, June 24-28, that the Hotel Somerset has been selected as headquarters of the Institute, where all the sessions will be held. Full details of the Convention arrangements will be given in the June PROCEEDINGS.

Resume of Business Transacted at the Meeting of the Board of Directors of the American Institute of Electrical Engineers, April 5, 1912

The following members of the Board were present: President Gano Dunn, New York; Past-Presidents Lewis B. Stillwell, New York, and Dugald C. Jackson, Boston; Vice-Presidents David B. Rushmore and Charles W. Stone, Schenectady, N. Y., W. G. Carlton, New York; Managers A. W. Berresford, Milwaukee, Wis., William S. Murray, New Haven, Conn., Severn D. Sprong, Brooklyn, N. Y., H. H. Barnes, Jr., New York, William S. Lee, Charlotte, N. C.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

Upon recommendation of the Board of Examiners 72 Associates were elected and 78 Students were ordered enrolled.

The following Associates were transferred to the grade of Member: Messrs. Edward E. Clement, Washington, D.C., Vladimir Karapetoff, New York, B. Parks Rucker, Charlotte, N. C., John H. Morecroft, New York, and H. M. Gassmann, Birmingham, Ala.

Upon recommendation of the Sections Committee the organization of a Branch was authorized at Lafayette College, Easton, Pa.

Mr. Richard O. Heinrich, of Berlin, Germany, a Member of long standing, who for many years has been active in the interests of the Institute, was appointed Local Honorary Secretary of the Institute for Germany.

The President announced that arrangements were being made for the presentation of the Edison Medal to Mr. George Westinghouse, to whom it had been awarded by the Edison Medal Committee last December, at the Boston Convention of the Institute, June 24–28.

The President announced the death of Professor Antonio Pacinotti, of Pisa, Italy, one of the Honorary Members of the Institute.

The Board unanimously adopted the following resolutions:

> The Board of Directors of the American Institute of Electrical Engineers learns with extreme regret of the death, on March 24, 1912, of Professor Antonio Pacinotti, of Italy, an Honorary Member of this Institute, and desires to place on record its sense of the loss sustained:
>
> This death removes a historic figure whose name will always occupy a great place in the annals of electrical progress, for his discovery, in 1860, of the principles of the modern continuous-current dynamo and its reversibility.
>
> The Board of Directors in behalf of the membership of the American Institute of Electrical Engineers hereby tenders its profound sympathy to the relatives of the deceased, to his colleagues, and to the Associazione Elettrotecnica Italiana for the loss of its Honorary President.

The New York Reception Committee reported that Honorary Member C. E. L. Brown had arrived in New York on Sunday morning, March 31st. As a mark of recognition by the Institute of his presence in New York, and for the purpose of presenting him with his certificate of Honorary Membership, a formal dinner had been planned for Thursday, the 4th of April. Mr. Brown having found it necessary to sail for Europe on the 2d, a dinner attended by members of the Board of Directors and several Past-Presidents was tendered him on the evening of Monday, the 1st of April, instead.

The President again referred to the importance of co-ordinating the activities of the various branches of electrical engineering and of the Institute's entering into more intimate reciprocal relations with existing electrotechnical societies. This policy had been the subject of favorable discussion at previous meetings, and resolutions commending it were adopted.

Upon the invitation of Mr. Thomas N. McCarter, president of the American Electric Railway Association, the President was authorized to appoint three representatives of the Institute upon a committee, of the American Electric Railway Association and other organizations, to consider the joint use of poles. The President appointed as the Institute's representatives upon this committee Messrs. Farley Osgood, of Newark, N. J., Percy H. Thomas, of New York, and F. B. H. Paine, of Buffalo, N. Y.

The desirability of holding a midwinter convention in New York during the winter of 1912–1913 was brought to the attention of the Board in a latter from Past-President Lewis B. Stillwell, and a resolution was adopted expressing the opinion of the Board that the interests of the Institute would be promoted by the holding of a general convention at Institute headquarters between January 1 and April 1, 1913.

The Committee on Relations of Consulting Engineers submitted a report, and in accordance therewith a resolution was adopted authorizing the committee to prepare a code of fees and rules of procedure and to confer with similar committees of other societies composed in whole or in part of consulting engineers. The President was authorized to appoint advisory members to the committee.

The report of Mr. Farley Osgood, representative of the Institute at the annual conference of the Electrical Committee of the National Fire Protection Association recently held in Boston, was submitted and publication of the report was authorized.

The invitation of the American Philosophical Society to appoint a representative of the Institute to attend its general meeting at Philadelphia on April 16 and 17, 1912, was accepted, and the President appointed Mr. H. A. Hornor, of Philadelphia, as such representative.

A. I. E. E. Meeting in New York, April 5, 1912

The two-hundred and seventieth meeting of the Institute was held in the Engineers Building, New York, Friday evening, April 5, 1912. President Dunn called the meeting to order at 8:20 o'clock, and introduced Mr. Frank J. Sprague, chairman of the Institute's Railway Committee, under whose auspices the meeting was held.

Mr. Sprague introduced Mr. Samuel Insull, president of the Commonwealth Edison Company of Chicago, who presented a paper on "The Relation of Central Station Generation to Railway Electrification," illustrated with large charts displayed on the platform and charts shown on the screen, of the lighting, power and railway loads of New York, Chicago and Boston.

President Dunn, after the presentation of the paper, stated that Mr. Insull had desired the discussion to be informal. The discussion was participated in by Messrs. John W. Lieb, Jr., Dugald C. Jackson, W. S. Murray, Charles P. Steinmetz, Lewis B. Stillwell, Charles A. Coffin, Benjamin F. Wood, Cary T. Hutchinson, Bion J. Arnold, Frank J. Sprague, and Samuel Insull.

Mr. Insull's paper will be printed in a subsequent issue of the PROCEEDINGS.

After the meeting had adjourned, most of those present went up to the Institute rooms on the tenth floor, for the smoker.

Constitutional Amendments

Ballots for the Constitutional amendments have been rapidly coming in but more are needed, to reach the minimum number required, in order that the vote may be considered.

The only opposition on the part of the Institute Sections to the amendments has come from the Detroit-Ann Arbor, Fort Wayne and Urbana Sections, which have passed resolutions objecting to the proposed schedule of dues for the three grades of membership.

Resolutions supporting the amendments have been passed, in most cases unanimously, by some of the largest Sections of the Institute, notably, Atlanta, Boston, Los Angeles, Philadelphia, Pittsburgh, San Francisco, St. Louis and Toronto.

The principle of different dues for different grades of membership has long been recognized in the Institute and in other societies in which members in the higher grades, presumably able to pay more because of the success achieved in their profession, are permitted to contribute more to advance their profession's interests.

Any increase in the Institute's income resulting from the adoption of the amendments is incidental, and the dues for each grade have been fixed at an amount comporting with the dignity and responsibility of each grade, but should there be a moderate increase in the Institute's income, resulting from the passage of the amendments, it would unquestionably be devoted to the increase of the amount of matter in the Institute publications and to building up the interests of the Sections.

The last date upon which ballots upon the amendments may be received at Institute headquarters is May 14th, and, therefore, members who have not already voted should do so promptly. If the balloting circular has been mislaid, a duplicate may be obtained upon application to Institute headquarters.

Report on Conference of Electrical Committee of National Fire Protection Association

The report of Mr. Farley Osgood, who had been appointed by President Dunn special representative of the Institute at the recent annual conference in Boston of the Electrical Committee of the National Fire Protection Association, was submitted at the meeting of the Board of Directors on April 5, 1912. The three features which Mr. Osgood considered of greatest interest to the Institute are presented herewith.

I. The grounding of secondaries was made compulsory, in line with the recommendations of a joint committee which discussed this matter shortly before the Conference, the Institute being represented at this joint committee meeting by Mr. Sever, Chairman of the Code Committee, and the changes which were approved are as follows:

Rule 15a. Neutral wire (may) *must* be grounded and (when grounded) the following rules must be complied with:

Rule 15a. Omit the following fine print notes:

(Inspection Departments having jurisdiction may require grounding if they deem it necessary).

(Two-wire direct-current systems having no accessible neutral point are not to be grounded).

Rule 15b. Transformer secondaries of distributing systems (should preferably) *must* be grounded, *provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed* (250) 150 *volts and* the following rules must be complied with:

Rule 15b.—2: When no neutral point or wire is accessible one side of the secondary circuit (may) *must* be grounded (provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts).

Rule 15b. Omit the following fine print note:

(Inspection Departments having jurisdiction may require grounding if they deem it necessary).

A new paragraph to be inserted to be known as 15b–4 to read as follows:

Where the maximum difference of potential between the grounded point and any other point in the circuit exceeds 150 volts, grounding may be permitted.

A fine print paragraph to be added after 15g to read as follows:

It is urged that water companies and departments in charge of water works allow the attaching of ground wires to their piping systems in the full confidence that the integrity of such piping systems will in no way be affected, whatever may be the normal voltage.

The *italicized* words are the new words which replace those shown in parentheses, and there are some clauses, as shown, which come out entirely.

II. The committee report on Rule 1-d recommended changes in the second and third paragraphs of this rule as follows:

Rule 1-d. Change second and third paragraphs to the following:

For two-wire direct-current generators, single pole protection will be considered as satisfying the above rule, provided that the safety device is so located and connected, that the means for opening the same is actuated by the entire generator current, and the action thereof will completely open the generator circuit. If a generator, not electrically driven, has one terminal grounded, the safety device above mentioned must be placed in the grounded lead.

For three-wire, direct-current generators, compound or shunt wound, a safety device must be placed in each armature lead and so connected as to receive the entire current from the armature. Fuses will not be acceptable.

The safety devices must consist of either:

(1) A double pole, double coil overload circuit breaker, or

(2) A four-pole circuit breaker connected in the main and equalizer leads and tripped by means of two overload

devices connected one in each armature lead.

The safety devices above required must be so interlocked that no one pole can be opened without simultaneously disconnecting both sides of the armature from the system.

The reason for the change, as suggested, was that the Committee believed that a protective device placed in the ground or negative lead, instead of in the positive lead, would save the machine from injury and lessen the liability of fire in case a breakdown in the positive lead between the machine and the switchboard should occur.

The opinion of several present was that the liability of failure of the positive lead between the machine and the switchboard, in present day construction is not sufficiently great to warrant such a radical and somewhat expensive change in our present methods of wiring, and there were enough who agreed in this view to cause the entire matter to be referred back to the Committee for further consideration, with the recommendation that an expression of opinion be obtained from the American Electric Railway Association concerning this proposed change.

III. The desirability of having, in the Electrical Code, specifications for outside wiring for high voltages up to the maximum limits, was urged by some of the Southern members, who made objection to the running of 110,000-volt transmission wires through the streets of cities, but some of those present believed that there was a question as to whether or not it was within the province of the Code to dictate in such matters, and a committee was appointed, to which the problem was referred. This committee was also asked to consider the desirability of saying nothing about such matters in the Code, and taking entirely out of the Code the whole of Rule 13. So no definite action in the matter of specifications was taken at this meeting, nor were they even discussed.

Associates Elected April 5, 1912

ARANA, VICTOR MANUEL, Electrical Engineer, Escuela Nacional de Antes y Oficos, Lima, Peru.

BALDWIN, JAMES HEWITT, Manager, Dulles-Baldwin Electric Drill Co., 220 Fifth Ave., New York, N. Y.

BARNES, ALBERT JOHNSON, Telephone Engineer, Maritime Tel. & Tel. Co., res., 19 S. Park St., Halifax, N. S.

BARTON, THEOPHILUS FISK, Engineering Specialist, General Electric Co., 30 Church St., New York, N. Y.

BEERS, CHARLES WASHINGTON, Electrical Engineer, Lehigh Valley Coal Co., Wilkes-Barre, Pa.

BETTISON, WILLIAM REESE, Captain, Coast Artillery Corps, U. S. Army, Fort H. G. Wright, Fishers Island, N. Y.

BLACK, WALTER ALEXANDER, Assistant Electrical Engineer, Fairbanks, Morse Electric Mfg. Co., Indianapolis, Ind.

BRUEGGEMAN, FRANK, Assistant Mechanical and Electrical Engineer, South Park Commissioners; res., 6411 Sangamon St., Chicago, Ill.

CAMPRUBI, JOSE, Foreign Dept., General Electric Co., Buenos Aires, A. R.

CARLSON, CHESTER LANE, Central Station Construction, Western Canada Power Co., Ruskin, B. C.

CARLSON, TORSE, Electrician, Almena, Kansas.

CARR, LUCIEN, 3rd., Student Engineer, General Electric Co.; res., 44 Mall St., West Lynn, Mass.

COLE, WILLIAM HENRY, Superintendent, Street Engineering Dept., Edison Electric Illuminating Co., Boston, Mass.

CURTIS, GEORGE SCOTT, Assistant Superintendent, Public Service Electric Co., res., 77 Ward St., Paterson, N. J.

DAVIES, GUY ADDLESTON STAFFORD, Shift Operator, Shawinigan Water & Power Co., Shawinigan Falls, Quebec.

Delafield, Clarence E., District Manager, Crocker-Wheeler Co., 201 Devonshire St., Boston, Mass.

Dequine, Louis Edward, Assistant to General Superintendent, Madison Gas & Electric Co., res., 435 N. Murray St., Madison, Wis.

Desbaillets, Charles Jules, District Engineer, Canadian Westinghouse Co., Ltd.; res., 71 Columbia Ave., Westmount, Montreal, Que.

Drees, Clemens John, Member of firm Arkansas Electric Co., 119 Louisiana St., Little Rock, Ark.

Dudley, Wray, Electrical Engineer, General Electric Co., Oliver Bldg., Pittsburgh, Pa.

Edgar, William Hume, Sales Agent, Western Electric Co., 115 Purchase St., Boston, Mass.

Egan, Francis Desales, Electrical Superintendent, Pittsburgh Crucible Steel Co., Midland, Pa.

Fernald, Benjamin Gravely, Sales Agent, General Electric Co., Oliver Bldg., Pittsburgh, Pa.

Francis, Howard Lewis, Superintendent of Buildings, Mexican Light & Power Co., res., 6a de Balderas, 79 Mexico City, Mex.

Gallivan, John Daniels, Operator, Hydraulic Dept., Isthmian Canal Commission, Pacific Division, Corozal, C. Z.

Geiger, Wayne Hunter, Chief Electrician, Berger Div., Public Service Elec. Co., 68 Gamewell St., Hackensack, N. J.

Glines, Earle Stanley, Assistant Chief Draftsman, Stone & Webster Eng'g. Corp'n., 147 Milk St., res., 242 Newbury St., Boston, Mass.

Goldsmith, Clarence, Assistant Engineer, Public Works Dept., 1–5 City Square, Charlestown, Boston, Mass.

Gray, George Francis, Engineer, Consulting Engineering Dept., General Electric Co.; res., 1328 State St., Schenectady, N. Y.

Gray, Ralph C., Commercial Engineer, General Electric Co., Witherspoon Bldg., res., 1832 Arch St., Philadelphia, Pa.

Hallock, Macy Orsen, Electrical Engineer, General Electric Co.; res., 68 Vine St., West Lynn, Mass.

Helms, Herman Henry Adolph, Mechanical Engineer, Aluminum Company of America, 99 John St.: res., 306 West 100th St., New York, N. Y.

Herbst, William B., Engineering Dept. Alleghany County Light Co., 435 6th Ave.; res., 1735 Jancey St., Pittsburgh, Pa.

Hicks, Leslie Robert, Electrical Engineer & Superintendent, Fall River Electric Light Co., 14 Bedford St., Fall River, Mass.

Hoskins, Homer Arthur, Student Engineer, General Electric Co.; res., 171 Nott Terrace, Schenectady, N. Y.

Hoyt, Jackson Campbell, Sales Manager, De Cew Company, Ltd., 614–16 Portage Ave., Winnipeg, Man.

Hoyt, Ray Stevens, Electrical Engineer, American Tel. & Tel. Co., 15 Dey St., New York, N. Y.

Jacobs, Gaskell Samuel, J. G. White & Co., San Francisco; res., 2327 Cedar St., Berkeley, Cal.

Johanny, Mathias G., Engineer, Ideal Electric & Mfg. Co.; res., 296 West 4th St., Mansfield, O.

Jones, Edgar George, Western Electric Co., 463 West St., New York, N. Y.

Kehoe, Arthur Henry, Engineering Dept., United Electric Light & Power Co., 1170 Broadway, New York, N. Y.

Kerr, Benjamin Warfield, Manager, Railway & Industrial Engineering Co., 701 Peoples Bldg., Pittsburgh. Pa.

Klockars, Carl Peter, Laboratory Assistant & Mechanician, Sachs Laboratories, Inc., 103 Allyn St., Hartford, Conn.

KITTREDGE, CARLYLE, Facilities Engineer, Michigan State Telephone Co.; res., 194 Philadelphia Ave., East, Detroit, Mich.

KUMMER, LUDWIG, Electrical Engineer, General Electric Company, res., 351 Tyler St., Pittsfield, Mass.

LOGAN, HARRY BACHELOR, President, Dossert & Company, 242 West 41st St.; res., 330 West 95th St., New York, N.Y.

LUNAN, HAVELOCK JAMES STANLEY, Assistant Superintendent, Sorel Light & Power Co., Sorel, Que.

LYALL, ARTHUR VINTON, Vice-President, Electro-Chemical Rubber & Mfg. Co.; Secretary, Stewart Automobile Co., 30 Church St., New York, N. Y.

MAC DERMOT, SIDNEY GUY, Superintendent, with W. N. Dietrich, 16 St. Sacrament St.; res., 632 St. Urban St., Montreal, Que.

MAGNUS, HENRIK C., Designing Engineer, General Electric Co., West Lynn; res., 51 Lawrence St., Linden, Mass.

MOORE, JOHN THOMAS, JR., Construction Engineer, Central Georgia Power Co.; res., 575 College St., Macon, Ga.

NASH, CHARLES ANSON, Control Engineering Dept., General Electric Co.; res., 841 Union St., Schenectady, N. Y.

PATTERSON, JOHN, Managing Partner, Sydney Electrical Engineering Co., 7 Wynard St., Sydney, N.S.W.

PATTON, RALPH CLIFTON, Designing Electrical Engineer, D. & W. Fuse Co.; res., 9 John St., Providence, R.I.

PHELPS, RALPH LAROSE, Manager, Pacific Coast Department, Safety Insulated Wire and Cable Co., 589 Howard St., San Francisco, Cal.

PROCTER, JOSEPH HAROLD, Instructor in Electrical Engineering, Agricultural and Mechanical College of Texas, College Station, Texas.

RADER, WALTER EARL, Division Superintendent, Cleveland Electrical Ill. Co.; res., 2168 Stearns Rd., Cleveland, O.

ROBISON, ARCH R., Northwestern Metals Co., Helena, Mont.

SCHLARBAUM, ALVIN, Assistant Engineer, Smith, Kerry & Chace, Galt, Ont.

SEGAR, RALPH LEROY, Electrical Engineer, Whitall Electric Co., Norwich, Conn.; res., 7 Granite St., Westerly, R. I.

SHEARER, HARRY FOSTER, Draughtsman and Construction Engineer, Smith, Kerry & Chace, 550 Confederation Life Bldg., Toronto, Ont.

STILL, ALFRED, Electrical Engineer, Lake Superior Power Co., Sault Ste. Marie, Ont.

STRONG, FREDERICK POOLE, Superintendent, Carolina Power & Light Co., Sandford, N. C.

SUTHERLAND, FLOYD DANIEL, Electrician, F. K. Stearns & Co., Jefferson Ave. & Bellevue St.; res., 316½ Parker Ave., Detroit, Mich.

UHL, WILLIAM FRANK, Hydraulic and Electrical Engineer, with Charles T. Main, 201 Devonshire St., Boston, Mass.

VALENTINER, GUSTAV, Eng'g. Dept., New York Edison Co., 55 Duane St.; res., 223 W. 106th St., New York, N. Y.

VESTAL, MAX, Chief Electrician, Yakima Valley Transportation Co.; res., 408 6th Ave., South, North Yakima, Wash.

WALLACE, ROBERT BRUCE, Electrical Engineer, St. Paul Gas Light Co., 6th & Jackson Sts., St. Paul, Minn.

WALLER, ALFRED ERNEST, Production Manager, Ward Leonard Electric Co., Bronxville; res., 184 Archer Ave., Mount Vernon, N. Y.

WILLIAMS, GEORGE FREDERICK, Correspondent, Westinghouse Electric & Mfg. Co., Boston; res., 81 Foxteth St., Brookline, Mass.

WILSON, ELMER JOSIAH, General Electric Co.; res., 463 Chestnut St., Lynn, Mass.

ZIMMERMAN, PETER CHRIS, Constructing Electrical Engineer, Zimmerman Supply & Construction Co., Corvallis, Ore.

Total, 72

Associates Transferred on April 5, 1912

The following Associates were transferred to the grade of Member in the Institute at the meeting of the Board of Directors held on April 5, 1912.

Edward E. Clement, Telephone Engineer, Patent Attorney and Patent Expert, Washington, D. C.

Vladimir Karapetoff, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

B. Parks Rucker, Consulting Engineer, Charlotte, N. C.

John H. Morecroft, Assistant Professor of Electrical Engineering, Columbia University, New York.

H. M. Gassman, Electrical Engineer, Tennessee Coal, Iron and Railroad Company, Birmingham, Ala.

Recommended for Transfer April 2, 1912

The following Associates were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on April 2, 1912. Any objection to the transfer of any of these Associates should be filed at once with the Secretary.

Alfred Still, Electrical Engineer, Lake Superior Power Company, Sault Ste. Marie, Ont.

John C. Lincoln, Lincoln Electric Company, Cleveland, Ohio.

Frederick L. Rhodes, Outside Plant Engineer, American Telephone and Telegraph Company, New York, N. Y.

James W. Young, Assistant Chief Engineer of Light and Power Department of Water Supply, Gas and Electricity, New York, N. Y.

Ralph D. Lawrence, Associate Professor of Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

William B. Hale, Telephone and Telegraph Engineer, Federal Telegraphs, Mexico City, Mexico.

Frank A. Laws, Associate Professor of Electrical Testing Massachusetts Institute of Technology, Boston, Mass.

Recommended April 24, 1912

Frederick A. Mott, Electrical Engineer, Wheeler Green Electric Company, Rochester, N. Y.

William C. Lancaster, Assistant Manager, The United Engineering and Contracting Company, New York, N. Y.

F. M. Farmer, Engineer, Electrical Testing Laboratories, New York, N. Y.

Judson H. Boughton, President, National Light and Power Company, St. Louis, Mo.

Henry N. Muller, Sup't of Distribution, Allegheny County Light Company, Pittsburgh, Pa.

N. Monroe Hopkins, Electrical Engineer, Washington, D. C.

S. Morgan Bushnell, Engineer, Contract Department, Commonwealth Edison Company, Chicago, Ill.

Elwood Grissinger, Consulting Engineer, Buffalo, N. Y.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before May 21, 1912.

11373	Brown, C. J., New York, N. Y.
11374	Hague, O. C. F., Montreal, Can.
11375	Holcomb, T.W., New York, N. Y.
11376	Trumbull, R., Philadelphia, Pa.
11377	Frederick, H. A., Princeton, N. J
11378	Hachard, A., Lynn, Mass.
11379	Haynes, W., Portland, Ore.
11380	MacLennan, T., Winnipeg, Man.
11381	Marcotte, E., Montreal, Can.
11382	Sheldon, K. B., Chicago, Ill.
11383	Tyng, J., Keokuk, Ia.
11384	Langmuir, I., Schenectady, N. Y.
11385	Grant, E., New York, N. Y.

11386 Bailey, G. A., Rochester, N. Y.
11387 Davies, H. C., Toronto, Ont.
11388 Clark, S. B., Portland, Ore.
11389 Anderson, J. B., Savannah, Ga.
11390 Weicker, H. C. W., Hermsdorf, Germany.
11391 Kelly, A. R., Seattle, Wash.
11392 Mazoomdar, T. C., Ghazipore, India.
11393 Burd, F. J., New York, N. Y.
11394 Bociau, E. H., Albany, N. Y.
11395 Conn, C. F., San Francisco, Cal.
11396 McGrath, M. K., Rome, Italy.
11397 Braentigam, H. P., Agricultural College, Miss.
11398 Eisenhauer, G., Passaic, N. J.
11399 Colvin, C. W., Portland, Ore.
11400 Kastner, C. K., Los Angeles, Cal.
11401 Kearin, M. P., New York, N. Y.
11402 MacCutcheon, A. M., Ampere, N. J.
11403 Ristine, C. S., Richmond, Va.
11404 Snyder, F. L. Columbus, Ohio.
11405 Ferguson, C. S., Duluth, Minn.
11406 Simpson, J. D., Toronto, Ont.
11407 Carter, R. C., West Lynn, Mass.
11408 Wady, G. E., Fruitvale, Cal.
11409 Boggs, L., Easley, S. C.
11410 Sealey, P. T., Puerto Barrios, Guatemala.
11411 Myers, C. E., Chaffee, Mo.
11412 Young, T. S., Toronto, Ont.
11413 Anderton, J. H., Seattle, Wash.
11414 Alexander, R. L., West Allis, Wis.
11415 Canfield, J. G., Dallas, Texas.
11416 Albert, W. V., Tatoosh, Wash.
11417 Harris, G. F., Portland, Ore.
11418 Kelly, J. T., Jr., Baltimore, Md.
11419 Pilgrim, E.W., Schenectady, N.Y.
11420 Takata, N. I., Fayettville, Ark.
11421 Morash, B. H., Boston Mass.
11422 Spooner, H. W., New York, N. Y.
11423 Kelly, R., Wilkinsburg, Pa.
11424 Guild, G. R., Fort Wood, N. Y.
11425 Gale, R. F., Philadelphia, Pa.
11426 McGinty, J. A., Atlanta, Ga.
11427 Hardin, L. H., Schenectady, N.Y.
11428 Clark, F. C., Wheeling, W. Va.
11429 Mullin, W. G., Columbus, Ohio.
11430 Agnew, P. G., Washington, D. C.
11431 Alexander, M. W., West Lynn, Mass.
11432 Breitinger, C. M., Chicago, Ill.
11433 Rogers, H.W. Schenectady, N.Y.
11434 Priest, E. D., Schenectady, N.Y.
11435 Van Horn, I. H., Cleveland, O.
11436 Stevenot, J. E., Manila, P. I.
11437 Townsend, C. H., Yonkers, N. Y.
11438 Filine, E. M., Boston, Mass.
11439 Iyengar, S. K., Bombay, India.
11440 Sturges, T. L., Jr., Newark, Del.
11441 Dimmer, L.G., Newark, Del.
11442 Everett, G. W., Rochester, N.Y.
11443 Fay, H. J. W., Boston, Mass.
11444 Elrod, M. C., Vancouver, B. C.
11445 Martin, J. C., Portland, Ore.
11446 Porter, C. J., Portland, Ore.
11447 Schoolfield, H. H., Portland, Ore.
11448 McNeill, W., Vancouver, B. C.
11449 Foung, G., Milwaukee, Wis.
11450 Wanderly, R., Pittsburgh, Pa.
11451 Ferrey, F. G., Boston, Mass.
11452 Troutman,H.A.,Philadelphia,Pa.
11453 Mullen, J. J., St. Louis, Mo.
11454 Shapleigh, B., St. Louis, Mo.
11455 Moloney, T. O., St. Louis, Mo.
11456 Menzin, A. L., San Francisco.
11457 Thompson, G., New York, N. Y.
11458 Bogle, J. C., Jr., Mt. Pleasant, Tenn.
11459 Sutton, J. W., Vallejo, Cal.
11460 Anderson, E., Minneapolis, Minn
11461 Drabelle, J. M., Cedar Rapids,Ia,
11462 Watts, T. S., Grand Forks, B. C.
11463 Finnigan, G. P., Richmond, Va.
11464 Winkeer, G. H., Jr., Erie, Pa.
11465 Weber, C.B., Jr., New York,N.Y.
11466 Whitmore, C. W., Lynchburg, Va.
11467 Cushman, P. A., Hartford, Conn.
11468 Weill, S. I., Portland, Ore.
11469 Schneider, J. J., Frankfurt, Germany.
11470 Proctor, J. A., Boston, Mass.
11471 Canan, W. D., State College, Pa.
11472 Doble, F. C., Boston, Mass.
11473 Joy, D. G., Toronto, Ont.
11474 Murphy, M. N., Omaha, Neb.
11475 Coughlan, R. J., La Gro, Ind.
11476 Bliss, O. J., Chicago, Ill.
11477 Kretsinger, W. K., Seattle, Wash
11478 Bailey, G. K., Wheeling, W. Va.
11479 Halas, J. V., Boise, Idaho.
11480 McDonald,R.G., Mono Lake,Cal.
11481 Riggs, R. L., Winnipeg, Man.
11482 Thayer, W. C., Dayton, Ohio.

Total, 110

Students Enrolled April 5, 1912

5061 Moser, L. E., Univ. of Illinois.
5062 Phillips, L. L., Univ. of Illinois.
5063 Walter, C. A., Penn. State Col.
5064 Rexwinkle, F. D., Univ. of Illinois
5065 Van Deuser, A. B., Univ. of Illinois.
5066 Anderson, C.T., Univ. of Illinois.
5067 Gray, F. J., Univ. of Illinois.
5068 Fick, C. W., Univ. of Illinois.
5069 Weil, M. E., Univ. of Illinois.
5070 Giddings, A. S., Univ. of Illinois.
5071 Work, C. W., New Hampshire Col.
5072 Bent, D.E., Mass. Inst. Technology.
5073 Loef, J. W., Univ. of Texas.
5074 Kern, P. E., Penn. State College.
5075 Fuller, E., Colo. Agr. College.
5076 Apgar, L. M., Univ. of Illinois.
5077 Pereira, D. de S., Ohio North. Univ.
5078 Stottler, M. W., Yale Univ.
5079 Hart, R. P., 2nd., Yale Univ.
5080 Tilton, O. A., Yale Univ.
5081 Bellows, R., Yale Univ.
5082 Hazeltine, H. L., Yale Univ.
5083 Wilberley, M. R., Yale Univ.
5084 Montgomery, H. E., Univ. of Ill.
5085 Neff, W. N., Univ. of Virginia
5086 Goulden, S. W., Univ. of Virginia.
5087 Ward, W. R., Univ. of Virginia.
5088 Prince, D. C., Univ. of Illinois.
5089 Oday, A. B., Syracuse University.
5090 Ingraham, E. B., Syracuse Univ.
5091 Crowell, E. P., Syracuse Univ.
5092 Barnard, G. H., Syracuse Univ.
5093 Richardson, L. L., Syracuse Univ.
5094 Shepherd, I. J., Univ. of Virginia.
5095 Lamb, J. C., Univ. of Virginia.
5096 Alexander, R. M., Ohio Northern Univ.
5097 Cartwright, K. C., Purdue Univ.
5099 Harbaugh, P. B., Purdue Univ.
5100 Jackson, D. J., Purdue Univ.
5101 Kallmeyer, A. W., Purdue Univ.
5102 Orem, R. H., Purdue Univ.
5103 Vial, C. H., Univ. of Michigan.
5104 Evans, W. J., Univ. of Toronto.
5105 O'Grady, J. H., Ohio Northern Univ.
5106 Tabb, W. T., Univ. of Virginia.
5107 Calcott, W. S., Univ. of Virginia.
5108 Otis, H. A., Univ. of Illinois.
5109 Bagley, G. D., Univ. of Illinois.
5110 Juley, J. P., Brooklyn Poly. Inst.
5111 Harmon, H. M., Univ. of Virginia.
5112 Hager, E. A., Armour Inst. Tech.
5113 Geist, H. F., Univ. of Illinois.
5114 Hays, D. L., Univ. of Illinois.
5115 Jewett, R. E., Univ. of Illinois.
5116 Grigsby, O. E., Univ. of Illinois.
5117 Peacock, J. T., Ga. School Tech.
5118 Albert, L. F., Univ. of Idaho.
5119 Mumma, R. W., Lafayette Coll.
5120 Steeper, T. P., Univ. of Kansas.
5121 Mehl, B. M., Univ. of California.
5122 Wright, C. E., Washington Univ.
5123 Pettengill, J. B., New Hamp. Coll.
5124 Porter, W.H., Ohio Northern Univ.
5125 Mason, E. M., Mass. Inst. Tech.
5126 Newberry, A. P., Univ. of Wash.
5127 Blouch, L. H., Penn. State Coll.
5128 Filbert, G. B., Cornell Univ.
5129 Brye, W. F., Cornell Univ.
5130 Hull, R. H., Univ. of Colorado
5131 Mason, M. A., Univ. of Colorado.
5132 Mayforth, J. H., Pratt Institute.
5133 Simons, A. M., Univ. of Illinois.
5134 Mock, B. R., Univ. of Kansas.
5135 Billings, J. H., Univ. of Toronto.
5136 Euler, H. J., Pratt Institute.
5137 Davidson, W.F., Univ. of Michigan
5138 Jinguji, G., Univ. of Illinois.

Total, 77

Addresses Wanted

Name	Former address
H. H. Bales,	Ashcroft, B. C.
H. H. Hess,	Hellertown, Pa.
Wm. A. Hirt,	Evanston, Ill.
F. C. Newell, Jr.,	38 Vesey St., New York, N. Y.
F. W. Randall,	Ellenville, N. Y.
J. W. Rutherford,	283 Summit Ave., Jersey City, N. J.
C. A. Tozer,	Spencerport, N. Y.
T. Philip Walker,	36 Burton Ave., Montreal, Que.
G. M. Willis,	25 E. Walton Place Chicago, Ill.

Members or Associates who can give information that may assist in obtaining any of these addresses are requested to communicate with the Secretary of the Institute.

Proposed Recommendations to County and Municipal Authorities Governing Transmission Line Construction.*

BY A. M. SCHOEN

Recent extensions and consolidations of power companies and the extensive development of hydroelectric properties in the South has made it imperative that both city and county authorities take thought as to what precautions shall be required of corporations where use is made by them of the public highways for their overhead lines. Most of the transmission lines are in connection with two or more plants operated in parallel and are erected with a view to serving large sections of the country. In order to find proper market, very considerable distances must be traversed and economy as well as efficiency demands operation at excessively high voltages. The two most popular differences of potential in this field have been 66,000 and 110,000 volts. In nearly every instance the power companies themselves have very wisely elected to avoid the public highways with their extra high tension lines and by purchasing and paying good money for private rights-of-way, minimize their liability to damage suits as the results of accidents to passersby in the vicinity of their lines, and it is difficult to understand how the same engineer who would not consider making use of the country highways, even though their use were freely proffered, would be quite satisfied to carry his 66,000 or 110,000-volt lines overhead through the streets of a city, even though these streets were among the least thickly inhabited. The only explanation is rank commercialism, and the city that allows this to be done is generally either caught napping or has been badly advised. Unquestionably these high-voltage lines can be so designed and erected as to reduce the initial danger to a practically negligible quantity, but the factor of safety that should be rigidly maintained is not to be relied upon with the large human element entering thereinto—commercialism will play its part here as elsewhere. Reasoning from the view point of convenience and a slight increase in efficiency, one can readily see why the company prefers to continue its high voltage lines into the vicinity of the center of the town if the distributing plant is already located there, as this may also tend toward an economy in operation, but it is a question of very considerable doubt whether this can compensate for the dangers to both life and property that may ensue from taking advantage of it. Even though every precaution be taken in the way of good mechanical construction and high dielectric strength, absolute immunity from breakage and leakage are impossible, and the likelihood of these increases with the age of the system. At the time of construction, having in mind possible accidents and the nature of the current used, every detail is carefully worked out and followed, but here, as elsewhere, familiarity breeds contempt, or at least carelessness, and as time passes, rotting poles, rusting metal, and nicked or cracked insulators are not so closely watched, wires of other systems are strung in proximity as convenience, economy or expediency may dictate, and the possibilities of trouble steadily increase. On the other hand, if the city grows along the route taken by this pole line and it becomes incumbent upon the telephone company or the fire alarm department to extend its lines paralleling those of the high-voltage system, the service is liable to be seriously effected, due to inductance and electrostatic conditions. Another feature to be considered where the original line voltage enters the city, is that there is no immediate control possible between the substation and the power plant, which may be one hundred miles or more away, and in case of accident, even though the breakers at the power plant go out, they would probably be again thrown in until the operator should become convinced of serious trouble on the lines.

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*Atlanta Section A.I.E.E., March 12, 1912.

Some two years ago, following a request of the Commissioners of Fulton County, Georgia, the writer in conjunction with Messrs. H. P. Wood, J. N. Eley and F. N. Miles, agreed to formulate a set of specifications to regulate the building of high-tension lines through Fulton County, and the result of the work of this committee, after being threshed out with the representatives of the various electrical interests in the state directly affected, is embodied in the following, which in the speaker's opinion forms suitable specifications for general recommendation to county and state officers:

SPECIFICATIONS

For municipal lines I would recommend either that a substation be erected outside of the city limits and a difference of potential not exceeding 6,600 to 11,000 volts allowed between overhead wires, or else if the extra high tension lines must be brought into the city, they be brought in underground. Where the overhead lines are used for voltages in the neighborhood of 6,600 to 11,000, I would recommend that the following specifications under general rules Nos. 1, 2, 3, 4, 5, 6, 7, 8, and 9, be followed:

GENERAL RULES

1. The pole line shall be confined to one side of the highway.

2. Where the highway is used, all power lines regardless of system or ownership shall be confined to the same side of the highway.

3. The lowest wire shall be at least 30 ft. (9.1 m.) above the ground at the lowest point of the system.

4. Lines shall be constructed with a factor of safety of two with the weather at zero deg. fahr., the line covered with sleet to a depth of one-half inch (13 mm.) and the wind velocity of 70 miles (112.6 km.) per hour.

The factor of safety for poles shall be:

Steel	3
Reinforced concrete	4
Completely creosoted wood	5
Other wood	6

The poles at the terminals of the portion of the high-tension line covered by these specifications shall be of such strength as not to break under maximum load conditions if any or all of the conductors in the spans outside of this portion should break.

5. Signaling systems or other systems carrying a normally innocuous current shall not be strung on the same side of the highway with power lines.

6. Where necessary to cross signaling systems or other wires carrying innocuous or low-voltage current, the construction shall be as follows:

A.—Short span construction; the total span length of the top system being less than the difference in height between the nearest wires of the two systems.

B.—The high-potential line shall be so strongly constructed with respect to poles, cross-arms, insulators, wires with other fixtures, that the liability of a high-potential wire coming in contact with a telephone wire is made negligibly small.

7. At angles or corners, unless tower construction, extra heavy poles shall be used with double cross-arm construction, also suitable bracing and suitable angle irons properly grounded and having sufficient mechanical strength and carrying capacity to hold up any wire coming against them. Such poles shall be substantially set and guyed and guy wires shall have strain insulators at two points—one near the pole and the other not less than ten feet above the ground.

8. Minimum separation between the high-potential lines and any other lines, meaning thereby the bottom wire of top fleet and the top wire of bottom fleet, shall not be less than 10 ft. (3.05 m.)

9. The insulator pins shall be of steel or any other metal having sufficient mechanical strength and durability wherever the voltage is in excess of thirty-three hundred (3,300).

Extra High Potential Wires. (*Over 11,000 Volts*). Cross-arms shall be of steel, or else equipped on the lower side with ground plate or metal strip of suitable mechanical strength and carrying capacity so arranged that any wire falling on the cross-arm will, upon burning through, be immediately dead grounded.

If wires are carried on suspended insulators below the cross-arm, a grounded arm of suitable strength and carrying capacity shall be arranged to catch the wires in event of their breaking away from their supports.

The grounded wire on the poles shall be protected to a distance of at least 10 ft. (3.05 m.) above the ground to prevent any possibility of danger to those on the highway.

Recommendation. Except where necessary to cross the public highway, companies erecting extra high potential lines should be confined to their private right-of-way.

Presentation of Honorary Membership to C. E. L. Brown

The distinguished Swiss electrical engineer, Mr. C. E. L. Brown, of Baden, arrived in New York March 31, on his way home from a trip round the world. The New York Reception Committee of the Institute had arranged for a dinner on April 4, to be made the occasion of the presentation to Mr. Brown of an engrossed certificate of honorary membership in the American Institute of Electrical Engineers, which distinction had been conferred at a meeting of the Board of Directors on January 12, 1912.

It was found that Mr. Brown had planned to sail for Europe on April 2. A large number of acceptances had been received for the dinner on April 4, and the change in date prevented a great many of the officers, who had planned to attend, from being present. On the evening of Monday, April 1, a party of ten met in the Tapestry Room at the Engineers' Club, when the resolutions adopted by the Institute recognizing the work of Mr. Brown were presented to him, engrossed on parchment, signed by President Dunn and Secretary Hutchinson, bearing the seal of the Institute and appropriately framed.

The dinner was a successful affair, and all present, including the guest of the evening, had something to say. Brief speeches in recognition and commendation of Mr. Brown's contributions to science and engineering were made by President Dunn, Past-Presidents Martin, Lieb and Stott, Mr. C. A. Mailloux, Messrs. Rugg, Scribner and Barnes, members of the Council, and by Mr. Brown's prospective son-in-law, Dr. Meyer Delius. Letters and telegrams of regret were received from Messrs. Sprague, Scott, Steinmetz, Duncan, Weaver, Stanley, Hering, D. C. Jackson and Morgan Brooks.

Power Transmission Discussed by the Schenectady Section

The meeting of the Schenectady Section on March 26 was devoted to a discussion of the "Economical Limits of Power Transmission."

The chairman, Mr. E. B. Merriam, first introduced Mr. E. A. Lof, who outlined the protective features of high-voltage transmission projects. Mr. Lof paid particular attention to the limiting characteristics of oil circuit breakers and stated that as the voltage increases, the size of these devices increases very rapidly. He also pointed out that steps are now being taken to eliminate automatic protection on the high-pressure side of the electrical power systems operating above 40,000 volts.

In the absence of Mr. T. A. Worcester, Mr. Lof presented the former's paper, which discussed the most economical voltage for power transmission. This limit is set partly by questions of economy and partly by questions of insulation. Some years ago, the limit of voltage was almost absolutely set by the largest insulators of the pin type which could be manufactured. The development of the disc insulators enabled voltages up to 140,000 to be used. Above this point, however, the number of insulator discs which must be put in series becomes so great that the length of the string becomes excessive. Moreover, as the voltage is increased, the potential gradient across the discs becomes more uneven. Therefore, it is important that insulator manufacturers develop a design which will more uniformly distribute the electrical potential between the various discs so as to make the design more economical, besides diminishing the length of string.

Another limiting feature due to voltage is the corona effect which, however, may be taken care of by increasing the size of conductors or by supporting them a sufficiently great distance apart. The former is limited by economical considerations while the latter is limited by permissible height of towers, length of cross arms or number of power lines, so that in effect, this also becomes a question of economy.

Mr. V. E. Goodwin, the next speaker, took up particularly the limits imposed by lightning protective apparatus. He described in detail the limits imposed by the multigap arrester, and the increase in line voltage which is made possible by the development of the aluminum cell arrester. He pointed out that on systems operating at pressures in excess of about 60,000 volts, the effects due to abnormal atmospheric disturbances were not nearly so perceptible as on the lower voltage systems. In addition, it has been found that the atmospheric disturbances are dissipated along the transmission line before entering the station, so that a smaller percentage of shut-downs due to atmospheric disturbances is recorded on high-voltage lines than on corresponding low-voltage ones.

Mr. H. R. Wilson spoke of the limits imposed by design of power transformers. He showed that in the past ten years the high-voltage rating of power transformers has increased from approximately 40,000 volts to 140,000 volts, while the capacity has increased in the same period from 2,000 to 14,000 kilovolt-amperes. He stated that the minimum capacity of transformers for power transmission work depends almost directly on the size of the high pressure winding, since for mechanical reasons there is a lower limit of size beyond which it is impossible to go in winding high-pressure coils. The upper limit of capacity is in part determined by the maximum permissible size of the device which can be shipped completely assembled. In some cases, as for instance the 14,000-kilovolt-ampere units previously mentioned it was necessary to assemble the machines at destination. Where only a few of such devices are installed, proper facilities are rarely obtainable for correct assembly, so that it is questionable if this scheme is advisable. Another objection to the large capacity transformers is the increased cost of keeping spare units. This is permissible on very large systems where a 14,000-kv-a. transformer represents only about 8 per cent of the total capacity, but where this represents 30 per cent or 40 per cent of the total capacity of the station, economy dictates the use of very much smaller units which may be more easily repaired and which do not require such a great capital investment in non-productive material.

Mr. R. C. Muir pointed out that the calculation of high-voltage power transmission lines includes a consideration of the fixed charges, line losses, upkeep and miscellaneous labor charges. Of these, the fixed charges are invariably the greatest. Anything which may be done to diminish these will result in a corresponding economy in operation. He also pointed out that the high load factor is exceedingly important in connection with water power stations and quoted figures for an installation of 100,000-kw. capacity where a load factor of 60 per cent would be required in order to successfully compete with a steam station whose fuel supply must be transported about 200 miles (322 km.)

Mr. R. E. Argersinger pointed out that the limits of high-voltage transmission are very much more narrow than the preceding speakers had intimated. He stated that protective devices such as lightning arresters were still in the experimental stage, since on one high-voltage line, for instance, of 62 service interruptions in eleven months, 30 were due to lightning disturbances. On another system operating at a moderate voltage, 22 out of 35 interruptions in about one year were due to lightning. He stated that in many cases the trouble was due to high frequency and that lightning arresters, so-called, at present only take care of high voltage. He pointed out in this connection the experiments of Mr. E. E. F. Creighton with high frequency where it is shown that a resonant condition may occur which will cause enormous voltage rises on systems.

Following the presentations by these speakers, the subject was generally discussed by Messrs. H. L. Smith, A. T. Thrupe, Campbell Macmillan, N. L. Rea, Moreland King, E. B. Merriam and C. Lichtenberg. They touched upon the various protective devices and other limiting features of power transmission, and the new devices for the protection of high-voltage circuits against high-frequency disturbances.

Past Section Meetings

ATLANTA

The regular meeting of the Atlanta Section held March 12 at the University Club was attended by 52 members and visitors. Chairman A. M. Schoen, chief engineer of the Southeastern Underwriter's Association, read a paper on "Proposed Recommendations to County and Municipal Authorities Governing Transmission Line Construction," which is reprinted elsewhere in Section I. Mr. J. N. Eley, consulting engineer, spoke on the subject of "Incandescent Lighting for Three-Phase Systems." Both addresses brought out considerable discussion.

BALTIMORE

The March meeting of the Baltimore Section was held on the twenty-second of the month, in the physical laboratory of the Johns Hopkins University, with an attendance of thirty-four. Mr. A. S. Loizeaux presided. Mr. F. E. Wynne of the Westinghouse Electric and Manufacturing Company gave an illustrated lecture on "The Economics of Electric Railway Operation," emphasizing, among other points, the importance of correct gearing.

The Section held its April meeting on the ninth, in the same place, as a joint meeting with the Baltimore Section of the National Electric Light Association. Mr. E. D. Edmonston of the engineering department of the Gas and Electric Company gave an interesting lecture on the recent A. I. E. E. trip to Panama. Mr. Edmonston exhibited a series of lantern slides showing the condition of the work at various points on the canal, and diagrams making clear the method of operating the lock gates, lowering and raising the vessels, and the electric mules used for haulage. The lecture was enjoyed by an audience of two hundred persons.

BOSTON

The Boston Section met on March 27 in the auditorium of the Edison Building. Sixty-five attended the meeting, at which Professor William L. Hooper presided. The proposed amendments to the Constitution were discussed, and the members went on record as being in favor of them. Mr. George K. Manson, chief engineer of the New England Telephone and Telegraph Company, then addressed the meeting on "Some Problems of Telephone Engineering."

The meeting of the Section on April 10, in the same place, was attended by 150 members and guests. Chairman Hooper appointed a nominating committee, as follows: Messrs. J. F. Vaughan, chairman, A. E. Kennelly, C. T. Mosman, I. E. Moultrop, and G. E. Ewing, to nominate Section officers to be voted for at the May meeting. Mr. George M. Bates of the Westinghouse Electric and Manufacturing Company presented a paper on the Panama Canal, illustrated with lantern slides, describing his recent trip to the Isthmus.

CHICAGO

The Chicago Section held a meeting on January 22, when Mr. R. J. Young presented a paper on "The Prevention of Industrial Accidents."

The Section held no meeting in February. On March 22 sixty members attended the meeting, when Mr. H. F. Smith presented a paper, "Some Notes on Producer Gas Power." Prof. Woodworth presided.

CLEVELAND

The Cleveland Section met for the regular monthly meeting on March 18 in the Chamber of Commerce Library. The chairman announced the appointment of Messrs. G. S. Merrill, A. C. Eastwood and H. L. Wallau on the nominating committee to report at the next meeting. Mr. C. W. Bender, of the engineering department of the National Electric Lamp Association, presented an illustrated paper on "Electric Train Lighting," describing the various systems now in use and pointing out the particular fields for which each one is best adapted.

FORT WAYNE

The regular March meeting of the Fort Wayne Section was held on the 14th, in the transformer testing room of the Fort Wayne Electric Works, Twenty-two members and visitors were present. Chairman E. A. Wagner was the speaker of the evening, on "Line Surges and Transient Voltages." After an introductory statement of the importance of induced voltages on high-tension lines and a reference to the study which has been given to these phenomena, the speaker discussed a few of the fundamental formulas covering such discharges. He then began an interesting series of demonstrations showing the effect of capacity and reactance on line voltages. The actual workings of the oscillograph were also demonstrated.

INDIANAPOLIS-LAFAYETTE

The first regular meeting of the Indianapolis-Lafayette Section was held March 22, when twenty-eight members met at the Glenalba Cafe at 6:30 for dinner. After dinner the meeting was called to order by Mr. O. S. More, chairman. No business was transacted. Mr. R. W. Pope, Honorary Secretary, was present and addressed the meeting, outlining the activities of the Sections and Section work, and also discussing the proposed amendments to the Constitution.

At 8:00 o'clock the meeting adjourned to the assembly room of the Commercial Club, where Mr. A. P. Allen read a paper on "The Telephone and the Public." Public announcement had been given of this meeting and about forty were present.

ITHACA

The meeting of the Ithaca Section in Franklin Hall on February 22 was devoted to the topic "The Rectification of Alternating Current." Professor F. Bedell presided, and forty attended the meeting.

Mr. J. B. Chaffee, Jr., presented a paper giving a comparative resume of current rectification by means of the motor-generator, the synchronous converter, the permutator, and the mercury arc rectifier.

Mr. F. G. Tappan exhibited in operation one of the small Wagner rectifiers, which had been loaned for the occasion by the manufacturers, and explained the principle of operation and pointed out its field of application. Special attention was drawn to the fact that in charging storage cells either terminal of the rectifier might be connected to the battery and the current delivered by the rectifier would automatically be caused to have such a direction as to charge the battery.

Professor G. S. Macomber gave a talk on the Murphy arc valve rectifier, its development, structure, operation and field of application. One type of the rectifier which is now on the market was exhibited in operation.

In opening up the subject of rectification of alternating current for general discussion Professor Bedell pointed out some facts regarding the development of the permutator and directed attention to its serious defect from a practical point of view, the revolving brushes.

The meeting of the Section on March 14 had for subject "The Production of Alternating Current of High Frequency," and was attended by 69 members, students and visitors. Professor H. H. Norris presided.

Mr. M. H. Leidy, '12, presented a brief resume of the various methods of producing alternating current, and the practical limit of frequency attainable by each.

Mr. L. H. Fuller, '12, gave a more detailed account of the "Le Pell arc" method of producing high frequency. An experimental run was made from which data were taken for plotting the volt-ampere characteristic of such an arc. An empirical equation, showing the relation of arc current to terminal e.m.f. in terms of constants of the circuit, the conducting gas, the terminal material surface, the length of arc and the strength of magnetic field, was discussed and checked by experimental evidence.

During the discussion which followed Mr. C. H. Tower described some experiences with very large Wehnelt interrupters of the Caldwell type, and Professor G. S. Macomber called attention to the great difference between the highest frequency obtainable by the methods described and the average frequency of the electromagnetic waves known as visible light; also the microscopic dimensions of the electric circuit which would be necessary in order to tune it for resonance at such a high frequeny as that of light.

LYNN

At the meeting of the Lynn Section on March 21, in Lyceum Hall, West Lynn, there was an attendance of 92 members, students and visitors. Chairman E. E. Boyer presided. After the secretary had read the report of the entertainment committee concerning the annual banquet, the chairman gave a brief outline of the speakers for the remainder of the season and of the work the Section proposes to carry on. The speaker of the evening was Dr. W. R. Whitney of the research department of the General Electric Company, whose subject was "The Development of the Incandescent Lamp during the Past Ten Years." Dr. Whitney described the rapid strides that had been made in the development of the incandescent lamp during this period, and pointed out how little work had been done previous to this time, although this type of illumination had been known for forty years. He also spoke at length on the manufacture of the tungsten lamp and told of many experiments that were being carried on to perfect the incandescent lamp.

MADISON

The regular meeting of the Madison Section was held on March 29 in the lecture room of the City Library. Chairman J. N. Cadby presided at the meeting, at which there was an attendance of thirty. Mr. H. H. Magdsick of the engineering department of the National Electric Lamp Association presented a paper on "Gas, Gasoline, Arc and Incandescent Electric Street Lighting."

MILWAUKEE

The Milwaukee Section of the A.I.E.E., the Milwaukee Section of the American Chemical Society and the Milwaukee Engineers Society held a joint meeting on March 13, at the Plankinton House. Mr. F. P. Ells presided, and there was an attendance of 110.

The speaker of the evening was

Professor C. F. Burgess of the University of Wisconsin, who gave a very interesting talk on the corrosion of iron and steel. After reviewing the several theories that have been advanced regarding the corrosion of iron, Professor Burgess outlined his own theory, which is based on the electrolytic action between different parts of the iron having different density. In the presence of moisture these particles of varying density and composition form electrolytic cells which start the corrosion.

Several lantern slides of samples showed the corrosion effect, and laboratory apparatus was exhibited which duplicated this corrosion on a larger scale. The speaker also touched briefly on the influence of protective coatings, such as the Sherardizing process, which he stated was the formation of an alloy between the protective metal and the iron. It was also pointed out that impurities, such as the addition of other metals to the iron, have sometimes a retarding influence upon the corrosion, but in most cases the protective material has to be added in such large quantities as to make the process uncommercial. This seems to be in direct contradiction to the electrolytic theory and therefore a very broad field is still open for investigation upon this subject.

During the discussion the influence of impurities, such as copper and nickel, added to the iron for protection against corrosion, was discussed more in detail, also the influence of protective coating, which, it was pointed out, would be valuable only as long as the coating could be kept on the iron. In many cases this is very difficult, such as on pipes which are buried in the ground and which are in great danger of corrosion on account of their being also subjected to the electrolytic action of stray currents from railroads and lighting networks. It was suggested that the laying of pipes in a wooden duct filled with tar or asphalt would be the best protection, but under modern conditions where city streets are crowded to their capacity with pipes and cables this method is not practicable, except in rare cases where the importance of the installation warrants the high cost.

PHILADELPHIA

There was an attendance of fifty at the regular meeting of the Philadelphia Section on April 8. The meeting was held at the Philadelphia Electric Company Building, Chairman H. C. Snook presiding. Communications were read from other Sections on the proposed constitutional amendments and they were discussed by Messrs. Stevens, Owens, Hering, Hoadley, Hornor, Pike, Snook, and Blum.

An illustrated paper on "Some Features of the Outdoor Installation" was presented by Mr. F. C. Green, of Pittsfield, Mass., and the discussion which followed was participated in by Messrs. J. J. Frank, Painter, Penrose, Kershner, Owens, Snook, Hoadley, Bonine, Hornor and Cheyney.

PITTSFIELD

The regular March meeting of the Pittsfield Section was held on the 14th at the Hotel Wendell. Mr. J. J. Frank presided, and there was an attendance of forty-six. Mr. L. F. Blume of the local plant of the General Electric Company gave a talk on "Transformer Connections for Three-Phase to Two-Phase Transformation." He described the various methods of such transformation and illustrated his talk with numerous lantern slides.

PORTLAND, ORE.

Twenty-six members and two visitors attended the regular meeting of the Portland Section held in the assembly hall of the Electric Building March 19, 1912.

Mr. Weber, the chairman, made a few brief remarks in regard to the 271st meeting of the Institute to be held in Portland April 16 to 20, 1912, and called upon the secretary to read the preliminary program giving a list of the papers and entertainment provided for as given in the leaflet which had been printed for distribution among the members of the Institute.

Mr. E. D. Searing presented a paper entitled " The Steel Tower Transmission Line of the Portland Railway, Light and Power Company," giving some very interesting details in regard to its design and construction. The attention of the members was called to the fact that there were peculiar conditions affecting the construction of this line so that the cost of construction cannot be considered as representative in any sense.

SAN FRANCISCO

The San Francisco Section held its regular monthly meeting on March 29, 90 members being present. The proposed amendments to the A.I.E.E Constitution providing for an additional grade of membership were discussed at length, and endorsed unanimously.

The subject of the meeting was a paper entitled " Recent Tests of Large Turbo-Generators and Boilers Recently Installed in the System of the Pacific Gas and Electric Company in Oakland," Messrs. Robert Sibley and R. F. Chevalier. Mr. Sibley gave details of turbine tests, prefacing his remarks by a brief outline of the elementary principles of the steam turbine. Mr. Chevalier dealt with the tests of the boilers, showing in detail, by means of lantern slides, the construction of the boilers used in the Oakland plant of the Pacific Gas and Electric Company.

Mr. Gano Dunn, the president of the Institute, was the guest of the San Francisco Section at an informal dinner given in his honor on the evening of April 13. Honorary Secretary Ralph W. Pope was also a guest. Mr. Dunn gave an interesting talk on the various matters of importance now before the Institute, particularly the constitutional amendments providing for the additional grade of membership and the appointment of the Secretary by the Board of Directors instead of his election by the membership, and the proposed International Electrical Congress to be held in San Francisco in 1915.

SCHENECTADY

The 109th meeting of the Schenectady Section was held in the Congregational Church Hall, 16 Jay Street, on March 26, under the auspices of the discussion meetings committee. The subject of " Economical Limits of Power Transmission " was discussed by the speakers. Chairman Merriam presided at the meeting, which was attended by 125 members and guests. Elsewhere in Section I will be found an abstract of the discussion.

The 110th meeting of the Section was held in Red Men's Hall on April 2.

Chairman Merriam introduced Mr. H. W. Buck, consulting engineer, of New York, who read a very interesting paper on " The Economical Combination of Steam and Water Power. "

Mr. Buck's paper dealt mainly with the cost of power as affected by the proper combination of water power and of steam power. He showed that by properly combining these two sources of energy, power could be produced at a lower cost than by utilizing either of them alone. He also pointed out that the fuel cost is a small item in either case, the principal item in the water power installation being the transmission line and in the steam power station, the economy of operation. He did not believe that large steam stations were more advantageously placed than small stations with regard to efficiency, since even comparatively small central stations could produce power efficiently if properly managed.

Mr. Buck showed that, because most American rivers have an exceedingly variable rate of flow, it is absolutely necessary in almost all cases to provide some form of auxiliary equipment in order to provide for supplying energy during the low water periods, since the old method of cutting off the consumers when the water is low can no longer be tolerated in American practise.

He showed some very interesting power diagrams of installations combining steam and water power and emphasized the necessity for an auxiliary equipment in order to make the projects profitable. The auxiliary equipment does not indicate that water power generation is unreliable, but it is necessary in order to make the installation economical and to provide against low water periods.

Mr. Buck's paper was discussed by Professor Charles F. Scott of Sheffield Scientific School and Messrs. W. L. R. Emmet, D. B. Rushmore, W. H. Peck and C. W. Stone.

About 200 members of the Section and guests were present at this meeting.

SEATTLE

The regular March meeting of the Seattle Section was held on March 16 in the assembly hall of the Chamber of Commerce. Mr. O. N. Wiswell was unavoidably detained and could not present his paper on "Hydroelectric Stations." Mr. N. A. Carle of the Puget Sound Bridge and Dredging Company presented a paper on "Construction of Dams," illustrating his subject with a moving picture film and a number of slides. A number of dam failures and their causes were illustrated and a reinforced concrete type of dam was shown which has been found very stable and which facilitates power house construction at moderate heads. The subject of electrolytic corrosion of reinforcement was brought out in the discussion which followed, participated in by Messrs. Ross, Howes, Lindsay, Lowe, Cooley, Moore and Crawford.

It was decided to postpone the April meeting one week, until April 27, in order that the Section might attend the Pacific Coast Meeting at Portland. Chairman J. D. Ross presided at the meeting, at which there was an attendance of 35.

ST. LOUIS

The regular monthly meeting of the St. Louis Section was held on March 13 in the rooms of the Engineers' Club, Mr. G. W. Lamke, Section chairman, presiding. Thirty-five members and visitors attended.

A paper on "Central Station Service for Industrial Plants" was presented by Mr. W. L. Rose, power engineer of the Union Electric Light and Power Company.

The application of motor drive in such industries as quarrying, brick manufacture, wood working, printing, etc., to displace steam or gasoline engine drive, was described in considerable detail. The question of industrial or group drive under different conditions of service was discussed and it was pointed out that it is advantageous to use central station service in preference to maintaining a private generating station. Most large central station companies maintain a department whose work it is to investigate and report on industrial power applications. When a factory is investigated a complete report is furnished the manager showing the proposed changes and the expected economies.

A number of lantern slides were shown, giving representative examples of motor drive.

The discussion following the reading of the paper was participated in by Messrs. Clarkson, Hunt, Dorney, McNair, Kraeuchi, Timmerman, Finch, Harrelson, Gutmann, Fish, and Newmayer.

* * *

A joint meeting of the St. Louis Section with the Engineers' Club of St. Louis was held on April 3, in the Engineers' Club Rooms. There was an attendance of 65 members and visitors.

The paper of the evening was on the subject "Unity Power Factor Motors," by Mr. A. H. Timmerman, of the Wagner Electric Manufacturing Company. The paper included a short discussion of the effect of power factor of load upon central station income. It was shown by means of curves how a low power factor reduces the central station income and increases the capital charge for a given output in kilowatts. The starting and operating characteristics of single-phase motors with squirrel cage rotors were compared with those of the repulsion type of motor. A brief explanation was given of the production of torque by means of a single-phase field. Finally, the starting and operating characteristics of single-phase motors of the compensated type were shown and explained with particular reference to a new type of unity power factor motor.

The paper was discussed briefly by Messrs. Langsdorf, Humphrey, Hunter and others.

On Monday, April 8, the St. Louis Section gave a dinner at the Planters Hotel in honor of President Gano Dunn. There was an attendance of more then 50 members and guests. After the dinner, Chairman Lamke introduced Mr. Dunn. who spoke at some length on the subjects of the new Committee on Patents of the Institute and the reasons for its appointment, the methods of electing officers, and the proposed amendments to the Constitution. These subjects are of very great interest to Institute members just at this time, and were particularly so to those members of the St. Louis Section who had the opportunity of hearing President Dunn talk. Several points of these subjects were also briefly discussed by Messrs. Langsdorf, Timmerman, Bruninga, and Clarkson of the local Section.

TOLEDO

The April meeting of the Toledo section was held on the 5th of the month at the Toledo Commerce Club, Chairman George E. Kirk presiding. Mr. J. Gilmartin exhibited some lantern slides showing different types of electrical measuring instruments. Mr. A. J. Gogel then gave a lecture on " Directive Radio-Telegraphy, " illustrated with blackboard sketches to make clear the various methods of directing Hertzian waves, showing the methods used by Marconi, Flemming, Fessenden, Braun, Bellini and Tosi, also showing curves representing the amount of energy sent in all directions. Following Mr. Gogel's lecture Mr. M. Neuber read and discussed Dr. Steinmetz's recent Institute paper, " Some Problems of High Voltage Transmission. "

TORONTO

The regular monthly meeting of the Toronto Section was held at the Engineers' Club on March 1. Chairman A. L. Mudge presided at the meeting, which was attended by 105 members, students and visitors.

A discussion took place on the amendment providing for three grades of Institute membership, and it was the opinion of the meeting that the amendment to the Constitution should be supported.

A motion was carried directing the Section executive committee to appoint a local standards committee which should suggest changes in the Standardization Rules of the Institute.

Mr. Julian C. Smith, chief engineer of the Shawinigan Water and Power Company, was to have presented his paper on their new plant, but as he was unavoidably prevented from being present he sent Mr. F. T. Kaelin, his chief assistant, who read the paper. Mr. Kaelin's paper gave a complete description of the plant, the construction of the coffer dam, and the putting into service of the new generators. At present there are installed two 15,000-kv-a. three-phase 60-cycle water wheel generators, each of which is connected to a 15,000-kv-a. three-phase 60-cycle 110,000-volt step-up transformer. Each tower line has been constructed to carry two three-phase circuits, and in Montreal there is one step-down transformer for each line. It was only fourteen months from the time work was started on this plant until it was put into commercial operation. The paper was completely illustrated with stereopticon views of the construction of all parts of the plant. A discussion was taken part in by Messrs. Mudge, Kemble, Brundidge, Bucke and a number of others.

URBANA

The regular monthly meeting of the Urbana Section was held March 13 in the electrical engineering laboratory of the University of Illinois, with Chairman E. H. Waldo presiding.

The feature of the evening was an original paper by Dr. Jacob Kunz on "The Theory of the Hysteresis Loop of Ferro-Magnetic Substances." His object in investigating this subject was to develop a rational formula for the calculation of hysteresis curves.

Dr. Kunz opened his paper by pointing out the close association between electricity and magnetism and emphasized the fact that with both alternating and direct current the magnetism in iron and all ferro-magnetic substances is not constant. He took as a basis for his investigation the behavior of the pyrrhotite crystal ($Fe_7 S_8$) and showed mathematically the effect on the molecules due to the intrinsic or internal field of the crystal itself combined with an external field. The final formula derived was considerably more complicated than the well-known Steinmetz equation.

At the meeting a communication from the Detroit-Ann Arbor Section relative to the proposed amendment to the Constitution, providing for a new grade of membership, was read. The almost unanimous opinion of the members present was in favor of uniform annual dues for all grades of membership, or else a $10 rate for Associates and Members and a $15 rate for Fellows. The members present favored the appellation "Fellow" for the new grade of membership.

There were present seven members and 23 students and visitors.

WASHINGTON, D.C.

The March meeting of the Washington Section was held on the 12th at the Telephone Building.

Honorary Secretary Ralph W. Pope addressed the meeting, having chosen for his subject "The Engineer in Politics." He briefly outlined the controlling principle upon which the great national parties had been organized at different periods since the foundation of the federal government.

These policies, he said, had no bearing upon municipal questions, and for this reason national politics should be eliminated from local elections. Engineering problems were the most important in municipal government, and therefore the trained engineer should strive to use his influence in the direction of higher efficiency in that field. The correct definition of politics, he said, was "the science of government," but through questionable practise in campaigning the title had been brought into disrepute. By taking an active part in the movement for the conservation of natural resources, the engineer had found that little could be actually accomplished except by cooperating with the government, and in aiding this cause, he had already directed attention to the influence which could be exerted in a good cause by the national engineering society.

Mr. Pope then called attention to the proposed amendment to the Constitution of the Institute for the establishment of a higher grade of membership. This recommendation by a special committee and the Board of Directors was in response to many requests from individual members, and also the official action of one of the Directors.

He said it was now up to the membership to decide whether the proposed plan was satisfactory. If defeated he believed the reasons for such action should be given, as the establishment of the department in the PROCEEDINGS called "The Forum" now offered an opportunity for suggestions and criticism.

Mr. J. H. Finney, Southern manager of the Aluminum Company of America, a member of the Washington Section, followed Mr. Pope with a few remarks on the same subject.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The regular meeting of the University of Arkansas Branch was held on March 19, with Mr. F. H. Oneal presiding. Twenty-one attended the meeting. Professor Dunn made an address on " Engineers in Ancient History. " He pointed out the fact that the engineer could not only derive pleasure from the study of ancient history but would have much to learn as to the mistakes and successful achievements of the ancient engineers. Mr. N. I. Takata read his thesis on " Multiplex Telephony, " and described some of his experiences in making laboratory tests.

ARMOUR INSTITUTE OF TECHNOLOGY

The Armour Institute Branch held its first March meeting on the 13th, in Chapin Hall, with an attendance of 38. Chairman L. H. Roller called the meeting to order at 8:30 p. m., and introduced the speaker of the evening, Mr. V. Pagliarulo, '12, whose subject was " The Electrical Equipment of the Metropolitan West Side Elevated Railway. " He gave a general description of the entire system, taking up in order the route and cars, the main generating station, and the substations. Following this description, wiring diagrams of the converter and battery substations were explained. In the discussion which followed many points of interest were brought up and explained in detail.

The meeting of the Branch on March 27, in the same place, was attended by thirty-six.

Mr. S. H. Cushing, statistician of the Public Service Company, addressed the meeting on " The Organization of a Public Service Corporation. " He explained briefly the need of organization in every undertaking, showing that this was especially the need of the electrical industry, because experience has proved that one large, well organized company can carry on the business of several small companies far more successfully than the several small companies could, working independently.

Mr. Cushing then gave an outline of the organization of the Public Service Company, illustrating the work of each department by explaining the procedure that followed the receipt of an application for service. He spoke of the education and training which the heads of departments and the men under them had, and of the qualifications necessary in the men who hold these offices. The speaker closed his address with an explanation of the percentage costs of a few of the things going to make up the total cost of energy to the consumer.

UNIVERSITY OF CALIFORNIA

The University of California Branch held a meeting on March 12, Chairman J. F. Pollard presiding. Mr. George J. Wheat spoke on the subject of " Prime Movers, " discussing the efficiency of various types and their respective advantages and disadvantages as sources of power for the generating of electricity.

At the meeting of the Branch on March 25, which was attended by 58 members, students and visitors, Professor H. F. Fischer read a paper on " The History of Electric Traction. "

COLORADO STATE COLLEGE

The Colorado State Agricultural College Branch met on March 11, and elected the editorial staff for the electrical engineering number of the *Collegian*, with Mr. Fuller as editor-in-chief. It was decided to hold the Electrical Show on April 20, with the expectation of an interesting exhibition, the electrical firms in Fort Collins cooperating to complement the resources of the college electrical engineering laboratory. The program of the evening consisted of a talk on

"The Graphical Solution of Engineering Broblems," by Mr. Rosencrants.

UNIVERSITY OF COLORADO

The meeting of the University of Colorado Branch on March 13 was attended by fifty-two members and visitors. Mr. A. L. Jones, district engineer for the General Electric Company, gave an illustrated talk on "Switchboards," from the earliest development down to the more recent and most fully equipped power boards.

At the meeting of the Branch on April 3, Mr. W. H. Edmunds, electrical engineer for the Denver and Interurban Railway, was the speaker. His subject was "Modern Development in Electric Railways," dealing particularly with the latest developments in gears and bearings, and the increased capacity of motors with forced ventilation.

UNIVERSITY OF KANSAS

The regular meeting of the University of Kansas Branch was held on March 13, with Chairman L. A. Baldwin presiding. Messrs. S. S. Schooley and E. E. Hartman gave digests of current electrical literature. Professor Gezelle spoke on the value, to the engineer, of public speaking ability, and urged engineering students to join a class in debate or public speaking.

The second March meeting of the Branch was held on the 27th. After the presentation of an abstract of current electrical literature by Mr. P. A. Meyer, Mr. H. C. Louderback of the transmission department of the Missouri and Kansas Telephone Company gave an interesting talk on "Problems in Transmission." He described the method of increasing the efficiency of a line by adding loading coils, making longer distances possible. He made the statement that by November 1, 1912, commercial connection would be established between New York and San Francisco.

LEHIGH UNIVERSITY

The Lehigh University Branch met on March 12, at the home of Dr. Drinker. Chairman W. I. Nevins presided at the meeting, at which forty-six were present.

The first paper was read by G. J. Shurts, '12, on "Electrolytic Corrosion." Very few casual observers realize the destruction wrought by stray currents in iron and reinforced concrete, and the speaker described many qualitative and quantitative tests which showed the behavior of these currents, and the remedies to nullify their effects.

A. G. Martin, '12, read the next paper on "Central Station Economy," which dealt with the various ways of profitably disposing of the waste steam in a power plant. One of the most lucrative methods is to run an ice plant with the steam, as this can be put into operation any time that the load factor is low and in this way the efficiency of the plant is vastly increased.

"Electricity in Coal Mining" was the subject of the final paper of the evening, read by W. J. Dugan, '13. He contrasted the use of electric power in the anthracite regions with its use in the bituminous regions.

UNIVERSITY OF MICHIGAN

At a joint meeting of the University of Michigan Engineering Society and the local Branch of the A. I. E. E. on March 19, Mr. H. M. Hobart of the General Electric Company read a paper on "Isolated Electric Power Stations." The paper was concerned chiefly with electric plants on shipboard, and the propulsion of ships by electric power.

Mr. Hobart brought out the point that, whereas the steam turbine is inherently a high-speed machine, the screw propeller shows very poor efficiency at high speeds, making it necessary to effect a compromise, *i.e.*, run the turbine at a slower speed than that at which it shows its greatest advantage, and the propeller at a higher speed that at which it operates most efficiently, or interpose reduction gears of high ratio. Reduction gears must be used even with the slowest speed turbines now built. The use of slow speed electric motors operated from high speed turbo-generators, to drive the propeller shaft, avoids the disadvantages of reduction gears, and affords a convenient and flexible system, easily controlled.

Such a system, now being perfected by the General Electric Company for installation in the U. S. collier " Neptune, " was briefly described and compared with other systems which use the turbine as a prime mover.

Mr. Hobart pointed out that whereas the land central station's peak load is of only a few hours' duration, an equipment for ship propulsion is called upon to furnish its maximum load for days and sometimes weeks at a time without a let-up.

A discussion by Professor Sadler of the marine engineering department and Professor Bailey of the electrical engineering department, followed the reading of the paper.

UNIVERSITY OF MISSOURI

The meeting of the University of Missouri Branch on March 11 was devoted to a discussion of the subject " Reducing Danger to Employees in Electric Power Systems," by Messrs. R. E. Powell and H. Friede.

Mr. Powell classified accidents according to their causes, showing what are the more common sources of danger, and how by proper rules, inspection, and the use of safety devices, these dangers may be minimized.

Mr. Friede spoke of the attitude of employers toward the matter of danger, and pointed out the necessity of a proper spirit of cooperation on the part of all operators and workmen. He then discussed the effect of legal action in the form of employer's liability acts, comparing the acts passed in several States.

In the discussion that followed a number of accident cases were cited that illustrated some of the points taken up in the papers.

At the meeting of the Branch on March 25 there was an attendance of thirty-seven. The meeting was addressed by Dr. J. H. Davenport, of the department of economics, on " Engineering and Social Service. "

Dr. Davenport defined a profession as an occupation in which a man sold his services directly to society. This at least was the original conception of a profession. In medicine and law this ideal may be considerably departed from, because the large rewards so often are for serving some individual, whose interests may differ from those of society. There is no necessary relation between pay and service to society. An engineer's opportunities come in refusing to be a party to undertakings that may work injustice or danger to the public, in endeavoring to see that fair dealing is the rule in all matters in which he has authority, and and as an educator of the public. In discussing rates for public service, Dr. Davenport questioned whether cost was necessarily the proper basis for charges, and cited as examples subsidising the use of water by low rates, and apportioning taxation so that it will fall on those who can most easily afford it.

MONTANA STATE COLLEGE

At the meeting of the Montana State College Branch on March 1 there were twenty-five present, of whom twenty were visitors. The meeting was devoted to a series of demonstrations. First there was shown wireless telegraph apparatus, including both portable and stationary receiving sets, then the three-galvanometer oscillograph of the electrical engineering department was shown in operation, as well as the high-tension transformer, and the Tesla oscillator.

UNIVERSITY OF NEBRASKA

The University of Nebraska Branch met on April 5 to elect student officers for the coming year. The chairman and secretary remain the same for the remainder of the year, Messrs. George H. Morse and V. L. Hollister, respectively. It was decided to spend May 3 and 4 at Omaha for the purpose of making inspection trips.

NEW HAMPSHIRE COLLEGE

At the meeting of the New Hampshire College Branch held on March 22, Professor Peabody of the Massachusetts Institute of Technology gave an illustrated lecture on "Some Types of Ships, Ancient and Modern."

The speaker began by describing the early Greek galleys and comparing them with the Roman and Venetian sailing ships. He brought out the distinctive features of all and showed their gradual development accompanying the changes in naval warfare. Then Professor Peabody described the merchantman of the middle ages and successive types finally leading up to the modern yacht.

There was an attendance of fifty-three at the lecture.

At the meeting of the Branch on April 8, Mr. Charles Norton, president of the Norton Grinding Company of Worcester, Mass., spoke on the subject "The Real and Unreal in Engineering." He said that it was the duty of the engineer to let everything he does represent the exact truth. He advised young engineers not to cultivate initiative to the extent of doing things in a different way simply because it is different. Success is determined by not ignoring what others have done in the past. On the other hand, young engineers should not be copyists, for the best kind of an engineer is the one who does creative work.

OHIO NORTHERN UNIVERSITY

The Ohio Northern University Branch held its regular monthly meeting on April 4. Mr. C. R. Moore's paper on "Air Gap Flux Distribution in Direct-Current Machines," printed in the March PROCEEDINGS, was read in abstract by Mr. F. M. Billhimer and discussed by Messrs. J. M. Ashley and H. D. Bruhn. Dr. C. P. Steinmetz's paper on "Some Problems of High-Voltage Transmissions," printed in the March PROCEEDINGS, was read in abstract by Mr. G. L. Carlisle and discussed by Mr. T. H. Frankenberry and Professor D. D. Ewing. A general discussion of both papers followed.

On April 11, thirty-one members of the Branch made an inspection trip to Springfield, Ohio, where the factories of the Robbins and Myers Company, James Leffel and Company, and the Foos Gas Engine Company, were visited. The municipal power plants of Springfield and Bellefontaine, Ohio, were also visited. In the Bellefontaine plant are two 92-kv-a. three-phase, Fort Wayne alternators driven by a 225-h.p. Diesel oil engine. The alternators are run in parallel at night for peak load. For the day previous to the visit, the total output of the plant was 1,851 kw. with an oil consumption of 211 gallons, oil costing them 2½ cents per gallon, net. The efficiency of the plant is therefore very high, as can readily be seen. Professor Ewing conducted the trip.

OHIO STATE UNIVERSITY

The meeting of the Ohio State University Branch on March 14 was addressed by Messrs. J. H. Post and C. E. Jennings, who described their work of the past summer on assembling and testing dynamos. Professor Hunt moved that an amendment to the constitution of the Branch be drawn to provide for the election of officers at the first meeting in April. The motion was seconded but laid on the table until the succeeding meeting.

OKLAHOMA A. AND M. COLLEGE

The Oklahoma Agricultural and Mechanical College Branch held a meeting on March 30, when three Institute papers were read: "Comparative Costs of 25-cycle and 60-cycle Alternators,"

C. J. Fechheimer; " The Relative Costs and Operating Efficiencies of Polyphase and Single-phase Generating and Transmitting Systems," H. M. Hobart; and " Some Problems of High-Voltage Transmissions," C. P. Steinmetz. Following these, there was a discussion on " Illumination."

OREGON AGRICULTURAL COLLEGE

At the meeting of the Oregon Agricultural College on March 7, Professor E. R. Shepard lectured on " The Great Men of Science."

PURDUE UNIVERSITY

The Purdue University Branch of the A. I. E. E. met for the second annual banquet at the Hotel Lahr on the evening of March 23. Eighty-five plates were laid for the banqueters, most of whom were students. Dean C. H. Benjamin of the Engineering Schools was toastmaster and the main discourse of the evening was delivered by Mr. A. D. Bailey of the Commonwealth Edison Company of Chicago, who responded to the toast, " Engineers." He called attention to " true service " as the greatest privilege which a man may have. Other toasts were responded to by Professor C. F. Harding, representing the faculty, Professor G. A. Young, the alumni, and Mr. F. A. Mayfield, the student membership. The event was a most enjoyable one, admirably fulfilling its purpose of promoting good fellowship among men interested in the same lines of work.

At the meeting of the Purdue Branch on April 2 several short papers on " The Electrical Refining of Metals " were presented by seniors in the School of Chemical Engineering. The first paper, by Mr. C. H. Best, dealt with lead refinement. Processes for lead refinement fall under two heads, one in which the action is electro-thermic and the other electrolytic. It was pointed out that in the actual production of lead from its ores the old smelting process is the one used commercially, when used at all. Electrical processes are for the purpose of refinement and separation of the metals.

Mr. J. R. Turner, in a paper on the production of aluminum, followed the development of the aluminum industry from the time when a pound of aluminum produced by costly chemical processes cost several dollars, to the present time when electrical processes have reduced the price per pound to a few cents. The electric furnace now used combines the electro-thermic and electrolytic actions, heat being originally furnished by an arc between the same carbons which afterward act as electrodes in electrolysis. Another method uses salts of aluminum which are more easily fusible and the heat is supplied from without, the action being wholly electrolytic. Either of these processes gives a cheap, pure, product. The great problem at present is to adapt the more common clays to electrolytic reduction.

The processes involved in the smelting of iron ores by electrical means were described by Mr. M. M. Inskeep. These methods, it was pointed out, can be economically used on a commercial scale only where the ores are of unusually high grade and fuel expensive. The method has found favor in Sweden, where the depletion of the forests and abundant water power have caused producers to turn to electrical processes.

Mr. L. E. Powers spoke on the electrolytic production of gold and silver. The three usual methods of separating gold from its ores employ mercury, chlorine or potassium cyanide. The first is not applicable to some ores and the other two are wasteful of the chemicals. By an electrolytic process, however, the expensive solvent may be recovered and used again. The alloys of gold and silver thus obtained may then be separated by a second electrolytic process.

The production of electrolytic copper was discussed by Mr. W. W. Pettibone. Commercially, the ores of copper which are widely distributed are reduced to a rather impure mass by smelting and, to refine this, the usual method is to cast the crude metal into plates which are the anodes in an electrolytic bath. With conditions properly maintained, nearly pure copper will be deposited at the cathode. Various other metals are precipitated in the process as a sludge, and the valuable ones are afterwards separately recovered.

Forty were present at this meeting.

ROSE POLYTECHNIC INSTITUTE

The regular meeting of the Rose Polytechnic Institute Branch was held on March 28, in the physical laboratory of the Institute.

Mr. Harry C. Uhl, of the senior class, read an original paper on " High-voltage Transmission " in connection with the article of Dr. Steinmetz, " Some Problems of High-Voltage Transmissions," appearing in the March PROCEEDINGS, which was followed by a general discussion as to the manner in which the insulator acts as a condenser.

Mr. William W. Reddie, of the senior class, gave a very comprehensive review of the paper by Mr. Charles R. Moore, in the March PROCEEDINGS, " Air Gap Flux Distribution in Direct-Current Machines."

STANFORD UNIVERSITY

The Stanford University Branch held a meeting on February 29 at which there was an attendance of 32. Messrs. H. Mullen and T. J. Easler gave a talk on the development of the electric furnace, illustrated with a series of sketches. An interesting discussion followed the talk.

TEXAS A. AND M. COLLEGE

A regular meeting of the Texas Agricultural and Mechanical College Branch was held on March 6.

Mr. J. R. Bozeman gave the first talk of the evening, on " Fuels for Power Plants." Mr. N. H. Hunt then read a paper on the " Testing of Power Plants." Professor Wooton, in his discussion on " How to Become a Successful Engineer," explained how to increase the efficiency of power plants.

Thirty-two members and visitors attended the meeting.

THROOP POLYTECHNIC INSTITUTE

The regular meeting of the Throop Polytechnic Branch on March 2 was addressed by Professor H. Perkins, who delivered an illustrated lecture on " The Mountains of Southern California and Their Resources." Twenty-eight were present at the meeting.

Three papers were presented at the meeting of the Throop Polytechnic Branch on April 6. Professor H. E. Clapp delivered an illustrated lecture on " Mining Machinery and Ore Refining." Mr. George A. Damond spoke on " Success and the Value of a Technical Education." Mr. Ray Catland gave a short talk on " The Tesla Turbine," after which the meeting adjourned to the mechanical laboratory, where a working model of the Tesla turbine, made by Mr. A. F. Hill, was demonstrated. The turbine was first run under load and then disassembled.

UNIVERSITY OF VIRGINIA

The second meeting of the University of Virginia Branch was held in the main lecture room of the mechanical laboratory on April 3. After a short business session, during which a set of by-laws for the local organization were adopted, Professor Llewellyn G. Hoxton of the School of Natural Philosophy presented a paper on " The Measurement of High Temperature." Professor Hoxton avoided the more purely theoretical points, and selected those that were of special interest to the engineer. Stating that the most important methods of measuring temperature were by optical and electrical means, the application of solids, liquids, and gases to the former method was first explained. It was pointed out that owing to the thermo-hysteresis of solids, they are not so well adapted to this purpose as are liquids and gases.

Of the electrical methods the thermo-couple affords the simplest as well as one of the most accurate means. By suitable connections it can be operated from a distance. It is used in practically all technical operations, and for scientific purposes, except in rare cases where the highest degree of accuracy is desired. In point of accuracy the ordinary thermo-couple is surpassed by the platinum-resistance thermometer. However, this is more expensive, more complicated, and more liable to disorders.

In conclusion, the branch of this subject known as "Optical Pyrometry" was explained. This takes advantage of the different lengths of heat waves radiated from a body at various temperatures, the ideal black body being the standard of comparison.

The discussion of the paper was of especial interest. Several members of the faculty present related personal experiences, showing the importance of knowing the temperature in such cases as the annealing of large guns, the temperature at various depths of grain elevators, and the application of the recording thermometer to some research work on transformer iron, where the iron was kept heated for some time. In the case of the grain elevators, thermo-couples are buried, and connected to the main office in a manner similar to a telephone exchange.

WASHINGTON UNIVERSITY

On the afternoon of March 27 the Washington University Branches of the A. I. E. E. and the A. S. M. E. made an inspection trip through the Ashly Street plant of the Union Electric Light and Power Company of St. Louis.

On the evening of March 28 the two Branches held a joint meeting, at which a paper entitled "The Central Power Station" was read by Mr. Hunter of the Union Electric Light and Power Company.

The paper was illustrated with views taken in the Ashly Street plant.

YALE UNIVERSITY

The seventh meeting of the Yale University Branch was held on March 22, in the Mason Engineering Laboratory. The meeting was addressed by Mr. E. R. Hill., who spoke on "The New York Tunnel Extension of the Pennsylvania Railroad." Mr. Hill is assistant to the Chief Engineer of Electric Traction, and has been connected with the great work of the New York terminal from its early stages. The talk was illustrated by a number of excellent lantern slides, and proved very interesting, especially to the members of the senior class, who were planning to visit the terminal on their inspection trip beginning March 27. There were 150 members and visitors present.

Personal

MR. W. N. SMITH is now connected with the Washington and Old Dominion Railway Company of Washington, D. C., as consulting engineer.

MR. G. C. THORNTON, formerly of Chattanooga, Tenn., is engineer in charge of construction of a cement plant being installed near LaFayette, Ga.

MR. RALPH D. MERSHON, consulting electrical and mechanical engineer, has removed his New York office from 60 Wall St. to 80 Maiden Lane—19 Cedar St.

MR. CHARLES H. KEEL of the Patent Department of the General Electric Company has recently been placed in charge of the Washington, D. C., office.

MR. F. H. COBLE, for the last five years chief of the testing department of the United Railways and Electric Company of Baltimore, has accepted a position in the engineering department of the Edison Electric Illuminating Company of Brooklyn, N. Y.

DR. FREIDRICH NIETHAMMER, professor of electrical engineering at the

Technische Hochschule, Brünn, Austria, well known as a writer on electrical engineering subjects, has been spending a month's vacation visiting points of interest in the eastern section of the United States and Canada.

Mr. W. A. Harding recently resigned his position as electrical engineer of the Treasury Mining and Reduction Company, New Mexico, and has again become connected with the work of the United States Reclamation Service. being stationed at the Elephant Butte Dam Project, New Mexico. Mr. Harding was for a time erecting engineer at the Roosevelt Dam for the U. S. R. S.

Mr. J. Tachihara, consulting engineer for the Inawashiro Hydroelectric Company of Japan, sailed on April 10 for England, after a trip through this country in which he inspected all the notable hydroelectric installations. While in Europe he will visit England, Germany, Norway and Sweden, and will return to the United States via England in June on his homeward journey.

Mr. Cecil P. Poole, who has been the junior editor-in-chief of *Power* for the past seven years, has severed his connection with that paper and will engage in consulting engineering in Atlanta, Ga., in partnership with Lamar Lyndon, of 60 Broadway, New York. The firm will operate as the southern branch of Mr. Lyndon's New York office, which will continue as heretofore. The Atlanta office will be conducted by by Mr. Poole.

Mr. George R. Wood, president of the Wood-Randolph Company, consulting electrical engineers of Pittsburgh, Pa., has been retained by the Berwind-White Coal Mining Company and allied interests, and has taken charge of their newly organized electrical department, with offices in the Arcade Building, Philadelphia. The Berwind interests operate over 30 mines in Pennsylvania and West Virginia, with electric plants totaling over 14,000 kw. capacity. Mr. Wood's interest in the Wood-Randolph Company has been acquired by Mr. Charles M. Means, chief electrical engineer for the Rochester and Pittsburgh Coal and Iron Company.

Obituary

Professor Antonio Pacinotti, of the chair of technological physics of the University of Pisa, Italy, inventor of the continuous-current dynamo and discoverer of the principle of its reversibility, died on March 24, 1912, in his seventy-first year.

The funeral in Pisa on March 27 was attended by scientists from all the countries of Europe, and over 30,000 mourners went in procession through the city. Cardinal Maffi, himself a distinguished man of science, officiated.

Antonio Pacinotti was born in Pisa, June 17, 1841. Under the direction of his father he early began the study of electromagnetism, and by the time he was 17 years of age had the principles of the direct-current generator well in his mind, constructing in 1860 the celebrated machine which ten years later was re-invented by Gramme, in 1870. After three years of experimentation with his models, Pacinotti published an illustrated description of his dynamo in the *Nuovo Cimento* in 1864, although it attracted little attention at that time. The machine described by the young Italian embodied for the first time the ring armature with its symmetrically grouped coils closed upon themselves and connected to the bars of a commutator, the brushes of which delivered a practically non-fluctuating current. In 1862 Pacinotti was appointed to the assistant professorship of astronomy at Florence, and having to renounce carrying out his electrical experiments on the enlarged scale he had planned, then prepared the description of his generator which appeared in 1864. In that year he received the professorship of applied physics at Bologna, and in 1873 was appointed professor of physics at Cagliara. At the Vienna exposition in 1873 he exhibited his dynamo model made in 1860, and for the first time received wide credit for his achievement, interest in which had meanwhile been awakened by the independent invention of the ring armature by Gramme in 1870. Early in his work, the Italian inventor discovered the reversibility of the dynamo of his creation, having expressly noted down that if the machine be supplied with energy from an outside source, it would run a motor. The reversibility of the Gramme machine, on the other hand, was not shown until 1873, when two similar dynamos were run as generator and motor at the Vienna exposition. Pacinotti resembled Faraday in his taste for research rather than technical exploitation, a characteristic which explains why his epoch-making invention lay dormant for years and was left to others to develop to practical and commercial efficiency. Dr. Pacinotti at the time of his death was professor of technological physics at the University of Pisa, and senator of the Kingdom of Italy. During the recent Turin International Electrical Congress he was tendered an enthusiastic ovation.

Professor Pacinotti was elected an Honorary Member of the American Institute of Electrical Engineers by unanimous vote of the Board of Directors, on January 12, 1912.

At the meeting of the Board of Directors on April 5 the following minute of respect to the memory of Professor Pacinotti was unanimously adopted:

> The Board of Directors of the American Institute of Electrical Engineers learns with extreme regret of the death, on March 24, 1912, of Professor Antonio Pacinotti, of Italy, an Honorary Member of this Institute, and desires to place on record its sense of the loss sustained.
>
> This death removes a historic figure whose name will always occupy a great place in the annals of electrical progress, for his discovery, in 1860, of the principles of the modern continuous-current dynamo and its reversibility.
>
> The Board of Directors, in behalf of the membership of the American Institute of Electrical Engineers, hereby tenders its profound sympathy to the relatives of the deceased, to his colleagues, and to the Associazione Elettrotecnica Italiana, for the loss of its Honorary President.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

A. L. A. List of Subject Headings. Ed. 3. Chicago, 1911. (Purchase.)

American Philosophical Society. General Index to the Proceedings. Vols. 1-50, 1838 1911. Philadelphia, 1912. (Exchange.)

American Telephone and Telegraph Company. Annual Report of the Directors to the Stockholders, 1911. New York, 1912. (Gift of American Telephone and Telegraph Company.)

Elektrizitat aus Kehricht. By Etienne de Fodor. Budapest, 1911. (Purchase.)

Elektrizitat in Hause. By George Dettmar. Berlin, 1911. (Purchase.)

History of the American Institute of Electrical Engineers Book Plate. n.p. n.d.

Iowa State College of Agriculture and Mechanic Arts. Bulletin No. 25. Engineering Experiment Station. Ames, 1911. (Gift of Iowa State College.)

National Conservation Congress. Proceedings, 1909, 1911 v. p. 1909, 1912. (Purchase.)

New York Board of Fire Underwriters. Report on Fire in the Equitable Building, January 9, 1912. n.p. n.d. (Gift of New York Board of Fire Underwriters.)

New York (State) Public Service Commission for the First District Proceedings. Vol. VI, 1911. New York, 1911. (Exchange.)

New York (State) Public Service Commission, Second District Annual Report. No. 4, volume III. Albany, 1911. (Gift of Ed, Caldwell.)

Railway Signal Dictionary. Ed. 2. New York, 1911. (Purchase.)

Society of Chemical Industry: List of Members, 1912. London, 1912. (Exchange.)

Tables of Equivalents of the United States Customary and Metric Weights and Measures. Ed. 3. Washington, 1906. (Gift of Bureau of Standards.)

UNITED ENGINEERING SOCIETY

Map of Central Asia Showing Extensions of Transcaspian Railway East of Tashkent (with mss. notes). (Gift of L. Goldmerstein.)

GIFT OF ENGINEERING NEWS

American Railway Association. Per Diem. New York, 1910.

American Water Works Association. American Standard Specifications for Cast Iron Water Pipe and Special Castings. n.p.n.d.

Connecticut Society of Civil Engineers. Proceedings. 1910. New Haven, 1910.

Federation of Trade Press Association in the United States. Annual Convention. 6th, 1911. Boston, 1911.

General Railway Signal Company. Catalogue and Price-list. Section 1-2. Buffalo, 1905.

Massachusetts Gas and Electric Light Commissioners. Annual Report 20th, 24th. Boston, 1905, 1909.

New England Water Works Association. Constitution and List of Members, 1909, 1910. Boston, 1909-10.

Ontario-Hydro-Electric Power Commission. Report 2d-5th. Ontario, 1906-07.

Pennsylvania Railroad Company. Annual Report. 63d, 1910. Philadelphia, 1910.

Rhode Island. Commissioner of Dams and Reservoirs. Annual Report, 1910. Providence, 1910.

Supervision of Street Railways in England and Prussia. (Reprinted from Annual Report of the Public Service Commission for the First District of the State of New York, 1908.) Albany, 1909.

TRADE CATALOGUES

Allgemeine Elecktricitats Gesellschaft, Berlin. Bull. No. 7—Electric switch systems for electric street railways. 16 pp.

Crocker-Wheeler Co., Ampere, N. J. Electric fans. 16 pp.

General Electric Co., Schenectady, N. Y. Bull. No. 4887—Small turbo-generator sets. 16 pp.

——Bull. No. 4911—Type *F*, form *K* 20 oil break switches. 15 pp.

——Bull. No. 4928—Searchlight projectors for commercial use. 24 pp.

Goldschmidt Thermit Co., New York. *Reactions* —First Quarter 1912—A quarterly periodical devoted to the science of alumino-thermics. 20 pp.

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Revised to May 1, 1912.

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Term expires July 31, 1916.

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Term expires July 31, 1915.

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Term expires July 31, 1913.

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Term expires July 31, 1912.

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CHARLES A. TERRY, New York.

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Term expires July 31, 1913.

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Term expires July 31, 1912.

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Term expires July 31, 1912.

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INSTITUTE REPRESENTATIVES.

Revised to May 1, 1912.

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EDWARD CALDWELL, New York.

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ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

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ROBERT JULIAN SCOTT, Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.
CLARE F. BEAMES, Bangalore, Mysore Province, India.

LIST OF SECTIONS.

Revised to May 1, 1912.

Name and when Organized.		Chairman.	Secretary.
Atlanta	Jan. 19, '04	A M. Schoen	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston	Feb. 13, '03	William L. Hooper	G. A. Rodenbaeck, 84 State St., Boston, Mass.
Chicago	1893	J. G. Wray.	
Cleveland	Sept. 27, '07	B. A. Stowe.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor	Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne	Aug. 14, '08	E. A. Wagner.	A. B. Morrison, 817 Nelson Street, Ft. Wayne, Ind.
Indianapolis-Lafayette	Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles	May 19, '08	O. H. Ensign.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Lynn	Aug. 22, '11	E. E. Boyer.	I. H. Sclater, General Electric Co., Lynn, Mass
Madison	Jan. 8, '09	J. N. Cadby.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico	Dec. 13, '07	W. H. Fiske.	H. S. Foley, Apartado 124 Bis., Mexico, D. F.
Milwaukee	Feb. 11, '10	F. A. Vaughan.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	Chas. L. Pillsbury.	Leo H. Cooper, 805 Metropolitan Life Bldg., Minneapolis, Minn.
Philadelphia	Feb. 18 '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg	Oct. 13, '02	K. C. Randall	E. L. Farrar, G. E. Co., Oliver Bldg., Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	G. Faccioli.	Erwin Stanley, General Electric Company Pittsfield, Mass.
Portland, Ore	May 18, '09	F. D. Weber.	H. R. Wakeman, 604 Electric Building. Portland, Ore.
San Francisco	Dec. 23, '04	S B Charters.	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady	Jan 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	J. D. Ross.	M. T. Crawford, Seattle-Tacoma Power Co., Seattle, Wash.
St. Louis	Jan. 14, '03	George W. Lamke.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo.
Toledo	June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto	Sept. 30, '03	A. L. Mudge.	W. E. Young, 212 King St., West, Toronto, Ont.
Urbana	Nov. 25, '02	E. H. Waldo.	F. G. Willson, University of Illinois, Urbana, Ill
Vancouver	Aug. 22, '11	F. D Nims.	E. M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D. C.	Apr. 9, '03	Earl Wheeler.	H. C. Eddy, Interstate Commerce Commission, Washington, D. C.

Total, 28

LIST OF BRANCHES.

Revised to May 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	C. E. Greene.	M. L. Johnson, College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L R Hulse, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	W. Fryberg.	R. L. Walsh, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
California, Univ. of..Feb. 9, '12	J. F. Pollard.	B.D.Dexter,1725 Euclid Ave.,Berkeley Cal.
Case School, Cleveland Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	W. H. Jefferson.	Oscar Plueddemann, 3133 Hackberry Street, Cincinnati, O.
Colorado State Agricultural College......Feb. 11, '10	D. E. Byerley.	A. A. Catlin, 626 So Meldrum St., Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	F. A. Fish.	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	L. J. Kieser.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	B F. Hillebrandt	W. C. Lane, Kansas State Agric. Col., Manhattan Kan.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of................Oct. 14, '10	W. H. Jaegle.	J. H Gaiser, 341 Harrison Ave, Lexington, Ky.
Lafayette College....Apr. 5, '12	H. J. Lockwood.	H. M. Bliem, Lafayette College, Easton, Pa.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa.
Lewis Institute.......Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	Benjamin Haskell	John E. Ash, University of Maine, Orono, Maine
Michigan, Univ. of...Mar. 25, '04	Walter M. Rennie.	LaVern E. Clapp, 432 Thompson St., Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo
Montana State Col...May 21, '07	J. Glen Luther.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts. Feb 11, '10	E. P. Speer.	W. H. Graham, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
Ohio Northern Univ. Feb. 9, '12	T.H.Frankenberry	R. L. White, 310 Ream St., Ada, Ohio.
Ohio State Univ.....Dec. 20, '02	C. S. Gordon.	C. E. Jennings, Columbus, Ohio
Oklahoma Agricultural and Mech. Coll.....Oct 13, '11	W. E. Dolde.	H. P. Cook, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.
Oregon State Agr. Col Mar. 24, '08	H Belknap.	W R Varner, Oregon St Agric College, Corvallis, Ore
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02		
Purdue Univ........Jan 26, '03	C F Harding	A L Topping, Purdue University, Lafayette, Ind
Rensselaer Poly. Inst. Nov. 12, '09	E. D N Schulte	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Rose Polytechnic Inst Nov 10, '11	Jerry H. Service, Jr.	David W. Jones, 911 North 8th Street, Terre Haute, Ind.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.......Feb 24, '05	W. P. Graham	A. R. Acheson, Syracuse University, Syracuse, N Y
Texas, Univ. of...... Feb. 14, '08	J. A. Correll	N. H. Brown, University of Texas, Austin, Tex.
Throop Poly. Inst....Oct. 14, '10	Frank C. Miller.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal.
Vermont, Univ. of... Nov. 11, '10	Walter L. Upson.	O Krupp, 65 North Bend St., Burlington, Vt
Virginia, Univ. of...Feb. 9, '12	Walter S. Rodman	Albert F. Edel, P. O. Box 115, University, Va.
Wash., State Coll. of..Dec. 13, '07	M K Akers	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ....Feb. 26, '04	Irwin L Cheney.	P S Stevens, Washington University, St. Louis, Mo.
Worcester Poly. Inst Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass
Yale University......Oct 13, '11	B. C. Beck	J. H. Shallenberger, 166 Vanderbilt-Scientific, New Haven, Conn.

Total, 43.

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

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THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol XXXI **June, 1912** No. 6

Annual Convention, Boston, June 24-28, 1912

The twenty-ninth Annual Convention of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS will be held in Boston, June 24 to 28, 1912.

Institute Headquarters

The official headquarters of the Institute during the Convention will be at the Hotel Somerset, where the technical sessions will be held. Members are requested to register at Institute headquarters on their arrival at the hotel. The following program has been arranged:

PROGRAM

Monday, June 24

8:30 P.M.

Reception and dance, Grand Ball Room, Hotel Somerset.

Tuesday, June 25

10:00 to 10:30 A.M.

1. President's Address, by Gano Dunn.
2. Introduction of President-elect, Ralph D. Mershon.

HIGH-TENSION TRANSMISSION SESSION
10:30 A.M. to 12:30 P.M.

3. *Determination of Corona Losses at High Potential*, by C. Francis Harding.
4. *Dielectric Strength of Air II*, by F. W. Peek, Jr.
5. *Electric Strength of Air III*, by J. B. Whitehead.
6. *Measurement of Voltage and Current over a Long Artificial Transmission Line at* 25, 60 *and* 420 *Cycles per Second*, by A. E. Kennelly and F. W. Lieberknecht.

PARALLEL MEETING
ELECTROCHEMICAL AND ELECTROPHYSICS SESSION
10:30 A.M. to 12:30 P.M.

7. *Electrolytic Corrosion of Iron in Street Soils*, by A. F. Ganz.
8. *The Electric Furnace*, by F. A. J. FitzGerald.
9. *Simplification of Electrothermal Calculations; the Watt and Thermal Ohm*, by Carl Hering.
10. *Vacua*, by W. R. Whitney.
11. *Metallic Tungsten and Some of its Applications*, by W. D. Coolidge.
12. *Characteristics and Applications of Vibration Galvanometers*, by Frank Wenner.
13. *The Convection and Conduction of Heat in Gases*, by Irving Langmuir.

2:00 P.M.

Visit to Power Stations.

3:00 P.M.

Meeting of Committee on Organization of International Electrical Congress San Francisco, Cal., 1915.

8:00 P.M.

Pop Concert, Symphony Hall.

Wednesday, June 26

JOINT MEETING WITH ILLUMINATING ENGINEERING SOCIETY

ELECTRIC LIGHTING SESSION
10:00 A.M. to 12:00 NOON.

14. *Problems of Interior Illumination*, by Bassett Jones, Jr.

15. *Relations of Illuminating Engineering to Electrical Engineering,* by Louis Bell.
16. *Demonstration of Some of the Relations of Color to Illumination Work,* by Herbert E. Ives.
17. *Industrial Illumination and Average Performance of Lighting Systems,* by C. E. Clewell.

RAILWAY SESSION

12:00 NOON to 1:00 P.M.

18. *Discussion on "Relation of Central Station Generation to Railway Electrification,"* by Samuel Insull.

2:00 P.M.

Visit to Massachusetts Institute of Technology and Harvard University.

8:00 P.M.

Conference of Officers and Section Delegates.

Thursday, June 27

JOINT MEETING WITH SOCIETY FOR PROMOTION OF ENGINEERING EDUCATION

EDUCATIONAL SESSION SYMPOSIUM

10:00 A.M. to 12:30 P.M.

19. *Introduction, Defining Scope and Purpose of Report of Educational Committee,* by J. P. Jackson.
20. *Industrial Education as Applicable by Electrical Manufacturing Corporations to their own Organizations,* by Charles P. Steinmetz.
21. *A Few Successful Types of Vocational or Industrial Education in the New England and Middle States, and Railroad Schools,* by Henry H. Norris.
22. *Telephone and Electric Operating Companies and other Industrial Schools in and about New York City,* by Samuel Sheldon.
23. *The Important Features of State Laws Relating to Publicly Supported and Controlled Vocational or Industrial Schools,* by Walter I. Slichter.
24. *Organization of the Technical College as Related to its Usefulness to the Industries,* by Ralph D. Mershon.

PARALLEL MEETING

TELEGRAPHY AND TELEPHONY SESSION

10:00 A.M. to 12:00 M.

25. *History and Development of Submarine Signaling,* by H. J. W. Fay.
26. *The Wiring of Large Buildings for Telephone Service,* by Fred L. Rhodes.
27. *The Vibrations of Telephone Diaphragms,* by Charles F. Meyer and J. B. Whitehead.
28. *Military Telegraph Lines Using the Polarized Sounder as Receiving Instrument,* by George R. Guild.

12:00 NOON to 1:00 P.M.

RAILWAY SESSION—CONTINUED

2:00 P.M.

Board of Directors' Meeting.

AFTERNOON

Entertainment features to be announced at the Convention.

7:00 P.M.

Official Institute Banquet and Presentation of Edison Medal.

Friday, June 28

ELECTRICAL MEASUREMENTS SESSION SYMPOSIUM

10:00 A.M. to 12:30 P.M.

29. *Measuring Stray Currents in Underground Pipes,* by Carl Hering.
30. *Electrical Transmission of Electrical Measurements, by* O. J. Bliss.
31. *Metering Large Direct-Current Installations,* by F. V. Magalhaes.
32. *A Tubular Electrodynamometer for Heavy Currents,* by P. G. Agnew.
33. *Measurement of Alternating Current of Low Value,* by M. G. Newman.
34. *Electrical Measurements with Special Reference to Lamp Testing,* by Evan J. Edwards.
35. *To Measure an Alternating-Current Resistance and Compare It with the Direct-Current Resistance,* by Edwin F. Northrup.

36. *Measurement of Energy with Instrument Transformers*, by Alexander Maxwell.
37. *Induction Type Indicating Instruments*, by Paul MacGahan.

PARALLEL MEETING POWER STATION AND INDUSTRIAL POWER SESSION

10:00 A.M. to 12:30 P.M.

38. *The Squirrel-Cage Induction Generator*, by H. M. Hobart and E. Knowlton.
39. *Power Efficiency of Rotating Electrical Machines*, by E. M. Olin.
40. *Operating Characteristics of Large Turbo-Generators, by* A. B. Field.
41. *Motor Starting Currents as Affecting Large Transmission Systems*, by P. M. Lincoln.
42. *Characteristics of a Large Unipolar Generator*, by B. G. Lamme.
43. *Single-Phase Induction Motors*, by W. J. Branson.
44. *Excitation of Alternating-Current Generators*, by D. B. Rushmore.

ELECTRICAL MEASUREMENTS SESSION—CONTINUED

2:00 to 500 P.M.

45. *Compensating Wattmeters*, by A. L. Ellis.
46. *Potential Transformer Testing*, by J. R. Craighead.
47. *Measuring Permeability with Alternating Current*, by L. T. Robinson and John D. Ball.
48. *Measuring Maximum Values in High Voltage Testing*, by C. H. Sharp and F. M. Farmer.
49. *Hot Wire Instruments*, by A. W. Pierce and M. E. Tressler.
50. *Incandescent Lamps as Resistances*, by T. H. Amrine.
51. *Resonant Circuit Frequency Indicator*, by W. H. Pratt and D. R. Price.
52. *Wheatstone Bridge-Rotating Standard Method of Testing Large Capacity Watt-Hour Meters*, by C. H. Ingalls and J. W. Cowles.
53. *The Testing of Instrument Transformers*, by P. G. Agnew and F. B. Silsbee.

POWER STATION AND INDUSTRIAL POWER SESSION—CONTINUED PARALLEL MEETING

2:00 to 5:00 P.M.

54. *Localizers, Suppressors and Experiments*, by E. E. F. Creighton and J. T. Whittlesey.
55. *The Runaway Speed of Waterwheels and its Effect on Connected Rotary Machinery*, by Daniel W. Mead.
56. *Relay Protective Systems*, by L. L. Elden.
57. *The Transient Reactions of Alternators*, by W. A. Durgin and R. H. Whitehead.
58. *Application of Electric Drive to Paper Machines*, by E. C. Morse.
59. *Electric Drive for Paper Machines*, by J. S. Henderson, Jr.
60. *Electricity on the Farm*, by Putnam A. Bates.

Entertainment

NOTE.—The Entertainment Committee will maintain an office during the convention at registration headquarters in the Hotel Somerset, where representatives of the committee will be prepared to give full information concerning the entertainment features.

Monday, June 24, 8:30 p.m., reception and dance in the Grand Ball Room of the Hotel Somerset, to which all members and their guests are invited.

Tuesday, June 25, 9:45 a.m. The ladies are invited to take a harbor trip, lunching at the Atlantic House at Nantasket Beach.

Tuesday, June 25, 2:00 p.m. Visit to the power stations of the Edison Electric Illuminating Co. of Boston, and the Boston Elevated Railway Co. at South Boston. This trip will be made by steamer and will give the members an opportunity of seeing the beauties of Boston Harbor.

Tuesday June 25 8:00 p.m. All members and their guests are invited to the Pop Concert in Symphony Hall, where all the tables on the floor have been reserved.

Wednesday, June 26. Ladies' day for independent action. The Entertainment Committee will upon application furnish guides, taxi-cabs or automobiles for those who may desire either to go shopping or sight-seeing around Boston.

Wednesday, June 26, 2:00 p.m. Visit to the Massachusetts Institute of Technology in Boston, and to Harvard University, in Cambridge.

Wednesday Evening. The ladies with their escorts are invited to attend a theater party.

Thursday, June 27, 9:45 a.m. An automobile trip will be taken by the ladies through the historic parts of Lexington and Concord, stopping for luncheon, and returning to the Hotel Somerset about 5 p.m.

Thursday Afternoon, June 27. This time is left open for independent action, but different entertainment features for this afternoon will be prepared by the Entertainment Committee and will be announced later.

The General Electric Company also invites all members desiring to visit its works at Lynn to take advantage of this time, and will, upon due notice to the Entertainment Committee, furnish transportation and guides for this trip.

Thursday, June 27, 7:00 p.m. Official Institute Banquet and presentation of the Edison Medal in the Grand Ball Room of the Hotel Somerset. Tickets Five Dollars ($5.00) per person.

Arrangements have been made by the Convention Committee with a number of golf clubs in and around Boston so that those desiring to play golf may have the privileges of the clubs during the stay in Boston.

Ladies' Entertainment

The events in the above program that will be of particular interest to the ladies are:

The reception and dance at the Hote Somerset Monday evening.

Harbor trip with luncheon at the Atlantic House at Nantasket Beach, Tuesday morning, returning about 5:30 p.m.

The Pop Concert in Symphony Hall on Tuesday evening.

Guides, taxi-cabs or automobiles will be furnished for ladies who wish to go shopping or sight-seeing around Boston on Wednesday.

Theater party, Wednesday evening.

All-day automobile trip to historic parts of Lexington and Concord, Thursday.

Official Institute Banquet, Thursday evening.

Transportation

No special transportation rates are available. Members should, therefore, consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

A representative of the Convention Committee will be at Institute headquarters during the convention to advise with and assist members and guests regarding their return accommodations.

Registration

Each member and guest, upon registration, will receive a badge bearing his or her name, to be worn during the convention for the purpose of identification. The registration headquarters will be at the Hotel Somerset, and the members are earnestly requested to register themselves and their guests promptly on arrival.

Hotel Arrangements

A special circular giving information regarding hotel accommodations has already been issued. Correspondence in regard to reservations should in all cases be addressed to Mr. Louis D. Gibbs, Chairman, Committee on Hotel Arrangements, 39 Boylston Street, Boston, Mass. Prompt application is desirable.

Resume of Business Transacted at the Meeting of the Board of Directors of the American Institute of Electrical Engineers, May 21, 1912

The following members of the Board were present at the meeting: President Gano Dunn, New York; Vice-Presidents Percy H. Thomas and W. G. Carlton, New York; Managers, A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., S. D. Sprong, W. S. Rugg, and Charles E. Scribner, New York; N. W. Storer, Pittsburgh, Pa., and Farley Osgood, Newark, N. J.; Treasurer George A. Hamilton, and Secretary F. L. Hutchinson.

The action of the Finance Committee in approving bills for the month of April, amounting to $8,070.52, and for the month of May, amounting to $11,125.13, was ratified.

The Finance Committee submitted its report for the year ending April 30, 1912, including a detailed financial statement showing the condition of the respective funds of the Institute, the receipts and disbursements for the year, the assets and liabilities, and a condensed cash statement. The report showed that the expenditures of the Institute have been considerably increased during the past year, due to the constantly broadening scope and activity of the organization, and particularly to the increased amount of technical matter published in the PROCEEDINGS and TRANSACTIONS resulting from the extension of the policy inaugurated a few years ago of holding Institute meetings in various parts of the country. Notwithstanding the increased expenditures made necessary by reason of these extended activities, there was a corresponding increase in income resulting in a surplus of income over expenditures for the year of $5,574.35. The Board voted its thanks to the Finance Committee for its work during the year and its successful management of the finances.

The Meetings and Papers Committee reported that the program of technical papers to be presented at the coming annual convention in Boston, June 24–28, had been completed. The number of papers to be presented is greater than that of any previous convention, making necessary the holding of parallel sessions during the entire convention. The program will include joint sessions with the Illuminating Engineering Society and the Society for the Promotion of Engineering Education.

The reports of the Board of Examiners of its meetings held on April 24th and May 14th were read and accepted.

Upon the recommendation of the Board of Examiners 175 applicants for admission to the Institute as Associates were elected and 66 students were ordered enrolled.

The following Associates were transferred to the grade of Member: Messrs. Herbert R. Harper, Melbourne, Australia; Frank F. Fowle, New York; Julien E. Dalemont, Hamilton, Ont.; John B. Klumpp, Philadelphia; Samuel H. Rippey, Philadelphia; and L. T. Robinson, Schenectady, N. Y.

The proposed amendments to the By-laws, prepared under instructions of the Board in order to bring the By-laws into conformity with the amendments to the Constitution providing for an additional grade of membership, were considered, and it was voted to adopt the amendments contingent upon the adoption of the amendments to the Constitution. (At the annual meeting of the Institute, held on Tuesday evening, May 21, the report of the Committee of Tellers was presented and the amendments were declared adopted. In the case of the Secretary amendment, 44 per cent of the membership voted and 92 per cent of the vote was affirmative. In the case of the Additional Grade amendment, 45 per cent of the membership voted and 83 per cent was affirmative).

The Board unanimously ratified the action of the President in issuing under date of May 3rd to all Members and Associates who had not at that time voted upon the proposed constitutional amendments, a second circular letter together with a duplicate ballot, this action having been in accordance with precedents established by the Board of Directors in connection with the balloting upon constitutional amendments in previous years.

The proposed rearrangement and decoration of Institute headquarters, which had been referred to a special committee at the previous meeting of the Board of Directors for consideration, was reported upon by the committee, which submitted plans and an approximate estimate of the expense, and recommended that an appropriation be made. The plan was approved by the Board, the appropriation was voted, and a special committee, consisting of Messrs. W. S. Rugg, Chairman, H. H. Barnes, Jr., and the Secretary, was appointed to complete the work. The principal purpose of the change is to increase the efficiency of the Institute office staff, and to make Institute headquarters more attractive and useful to out-of-town members by providing suitable reception and reading rooms, writing desks, facilities for conferences, etc.

A communication was read from the St. Louis Section, embodying certain comparative tabulated data and recommending the adoption of constitutional amendments concerning methods of nominating and electing officers af the Institute with a view to more equitable territorial representation. A resolution was adopted setting forth that the Board recognized the importance of the issues raised and directing that the report be printed in the next issue of the PROCEEDINGS, so that ample discussion might be had at the meeting of the Section delegates at the coming Boston convention. The report in full appears elsewhere in this issue.

The Patent Committee presented a report of the conference held in accordance with the call of the Patent Law Association in Washington on April 15th and 16th, which several of its members attended as authorized by the Board at its April meeting. This report was accepted and the President was authorized to appoint three conferees to attend future joint conferences.

Responding to the action of the Board at its March meeting a report was read from the Chairman of the Library Committee in reference to the proper display of the Wheeler collection of books now in the stackroom, and giving an estimate of the expense involved in making the necessary provision for more effective display. The report of the Library Committee was accepted, and the appropriation to cover the cost of the display of the Wheeler collection as outlined in the report was voted.

The President called the attention of the Board to the fact that a suitable official acknowledgment had never been made to the members of the Land and Building Fund Committee and to all the contributors to the fund, upon which the following resolutions were adopted:

WHEREAS direct official acknowledgment has not been made of all the contributions to the Land, Building and Endowment Fund of the Institute, and only a partial list of the contributors to the fund has been printed in the PROCEEDINGS, be it

RESOLVED that an alphabetical list of all contributors to the fund be printed in an early issue of the PROCEEDINGS, and be it

RESOLVED that the thanks of the Institute are hereby tendered to the contributors for enabling the American Institute of Electrical Engineers to comply with the terms of Mr. Carnegie's gift of the Engineering Societies Building, and be it further

RESOLVED that the thanks of the Institute are hereby tendered to the members of the Land, Building and Endowment Fund Committee, Messrs. Calvin W. Rice, Chairman in 1904, and T. C. Martin, Chairman in 1905 and 1906, and Messrs. John C. Barclay, U. N. Bethell, N. F. Brady, John J. Carty, Charles L. Edgar, Eugene Griffin, Samuel Insull, Francis W. Jones, John W. Lieb, Jr., J. H. McGraw, C. W. Price, Samuel Reber, Frank J. Sprague, Elihu Thomson, and J. G. White, for the able and energetic manner in which they conducted the work confided to them, which resulted in securing contributions to the fund from 1,600 members, aggregating $170,000.

The President announced the appointment of the following members of the Committee on Organization of the International Electrical Congress, San Francisco, 1915:

Charles P. Steinmetz, President.

Arthur E. Kennelly, Vice-President on Program.

C. O. Mailloux, Vice-President on International Relations.

W. D. Weaver, Vice-President on Organization.

Henry A. Lardner, Vice-President on Pacific Coast Relations.

Edward B. Rosa, Secretary.

Preston S. Millar, Treasurer and Business Manager.

(The above officers constitute the Executive Committee.)

REPRESENTATIVE MEMBERS

American Electric Railway Association: Henry W. Blake, Frank R, Ford, Edwin B. Katte, Henry G. Stott.

American Electrochemical Society: Charles A. Doremus, Carl Hering, Willis R. Whitney.

American Physical Society: Frederick Bedell, Charles F. Burgess, Edward L. Nichols.

Association Edison Illuminating Companies: Alex. Dow, Louis A. Ferguson, John W. Lieb, Jr., Joseph B. McCall.

Association of Railway Electrical Engineers: Jesse H. Davis, Charles R. Sugg.

Association Iron & Steel Electrical Engineers: Eugene Friedlander, Barton R. Shover.

Alabama Light & Traction Association: (Names to be announced later.)

Canadian Electrical Association: A. A. Dion.

Colorado Electric Light, Power & Railway Association: John F. Dostal, Franklin P. Wood.

Electric Vehicle Association of America: William H. Blood, Jr., Frank W. Smith, Philip D. Wagoner.

Electrical Testing Laboratories: Clayton H. Sharp.

Empire State Gas & Electric Association: Charles R. Huntley, Robert Meredith Searle.

Florida Electric Light & Power Association: (Names to be announced later.)

Franklin Institute: William C. L. Eglin, Robert Bowie Owens.

Illinois Electrical Association: Ernst Julius Berg, Francis Marion Sinsabaugh.

Illuminating Engineering Society: Edward Pechin Hyde, Van Rensselaer Lansingh, Louis B. Marks, Addams Stratton McAllister.

Indiana Electric Light Association: William D. Ray.

Institute of Radio Engineers: John L. Hogan, Jr., R. H. Marriott.

International Association Municipal Elec: William Brophy, Walter M. Petty.

Iowa Electrical Association: Arthur Hillyer Ford, Louis Bevier Spinney.

Louisiana Electrical Association: (Names to be announced later.)

Maine Electrical Association: Henry Wilson Eells, Walter Kierstead Ganong.

Minnesota Electrical Association: Paul Doty, Henry John Gille, George D. Shepardson.

Missouri Electric, Gas & Street Railway & Water Association: (Names to be announced later.)

National Bureau of Standards: Samuel W. Stratton.

National Electrical Contractors' Association: (Names to be announced later.)

National Electrical Inspectors' Association: Frank Rutter Daniel, Hugh T. Wreaks.

National Electric Light Association: Charles L. Edgar, Weldon W. Freeman, Frank W. Frueauff, John F. Gilchrist, Samuel Insull, T. C. Martin, Arthur Williams.

New York Electrical Society: Henry L. Doherty, George Heli Guy.

Ohio Electric Light Association: Francis Cary Caldwell, Frank Morrison Tait.

Society for Promotion of Engineering Education: Henry Hutchinson Norris, Samuel Sheldon.

Southwestern Electrical & Gas Association: Fred Marion Lege, Jr., Arthur Curtis Scott.

United States Navy Department: (Names to be announced later.)

United States War Department: (Names to be announced later.)

Vermont Electrical Association: H. D. Larrabee.

Western Society of Engineers: William L. Abbott, Harold Almert.

Wisconsin Electrical Association: Philip Harold Korst, Roy Henry Pinkley.

(List not complete)

PACIFIC COAST MEMBERS

San Francisco: Allen H. Babcock, Fred F. Barbour, Frank G. Baum, Charles N. Black, Augustus J. Bowie, Jr., Wallace W. Briggs, Charles W. Burkett, Samuel B. Charters, Harold W. Clapp, Safford K. Colby, Clarence L. Cory, Herbert W. Crozier, W. J. Davis, Jr., W. F. Durand, P. M. Downing, Augustus H. Griswold, Arthur H. Halloran, William W. Hanscom, George J. Henry, Jr., George C. Holberton, Andrew Murray Hunt, S. L. Griswold Knox, Sylvan J. Lisberger, John Martin, Wynn Meredith, George R. Murphy, Sam L. Naphtaly, Harris J. Ryan, Earl O. Shreve, Robert Sibley, Sidney Sprout, Frank H. Varney, Rudolph W. Van Norden, J. E. Woodbridge.

Los Angeles: Henry S. Carhart, George A. Damon, Edwin R. Davis, Orville Hiram Ensign, James A. Lighthipe, E. R. Northmore, J. E. Macdonald, Ezra F. Scattergood, Henry H. Sinclair.

Portland: Orin B. Coldwell, Leroy B. Cramer, James A. Cranston, Glen E. Kibbe, Paul Lebenbaum, W. D. Scott, W. S. Turner, Henry R. Wakeman, F. D. Weber, C. L. Wernicke.

Seattle: Magnus T. Crawford, John Harisberger, Edgar A. Loew, Carl E. Magnusson, Alvin A. Miller.

Spokane: John B. Fisken, D. L. Huntington, Robert Howes.

Corvallis: William A. Hillebrand.

Vancouver, B. C.: E. W. Breed, Robert F. Hayward, F. D. Nims.

MEMBERS AT LARGE

Comfort A. Adams, Bion J. Arnold, Howel H. Barnes, Jr., Clare F. Beames, Bernard A. Behrend, Louis Bell, Charles F. Brush, Harold W. Buck, John J. Carty, Alfred H. Cowles, Francis B. Crocker, Samuel E. Doane, Louis Duncan, Thomas A. Edison, Reginald A. Fessenden, John H. Finney, W. S. Franklin, James S. Fitzmaurice, A. S. Garfield, Bancroft Gherardi, Lester W. Gill, Winder E. Goldsborough, William G. T. Goodman, Henry Graftio, Richard O. Heinrich, L. A. Herdt, Peter Cooper Hewitt, John W. Howell, Henry H. Humphrey, Cary T. Hutchinson, Dugald C. Jackson. Peter Junkersfeld, Benjamin G. Lamme, Alexander S. Langsdorf, W. Arnold Layman, William S. Lee, Paul M. Lincoln, Samuel G. McMeen, Ralph D. Mershon, P. N. Nunn, H. F. Parshall, W. B. Potter, Michael I. Pupin, Samuel Reber, Calvin W. Rice, E. Wilbur Rice, Jr., David B. Rushmore, A. M. Schoen, Charles F. Scott, Robert J. Scott, Charles E. Scribner, George F. Sever, Peter William Sothman, Frank J. Sprague, G. O. Squier, William Stanley, Louis B. Stillwell, Charles Waterman Stone, Charles A. Terry, Elihu Thomson, Edward Weston, Schuyler S. Wheeler, James G. White.

ADVISORY MEMBERS

Representatives of foreign governments and technical societies. Not members of the Institute. (To be announced later.)

The annual report of the Board of Directors, which had been prepared by the Secretary, was approved and ordered presented to the annual business meeting of the Institute to be held the same evening. Reports of the various committees of the Institute, abstracts of which had been incorporated in the annual report, were received and ordered placed on file.

The meeting adjourned to meet at the call of the President during the annual convention in Boston, June 24–28, 1912.

THE FORUM

Dedicated to the Discussion of Institute Affairs

Proposed Plan for Nomination and Election of Institute Officers

The following report of a committee of the St. Louis Section was considered at the meeting of the Board of Directors held May 21, 1912 and was ordered published in the PROCEEDINGS, so that the subject may be fully discussed at the Boston Convention.

April 26, 1912

To the Members of the St. Louis Section of the American Institute of Electrical Engineers.

GENTLEMEN:

At the meeting of the St. Louis Section held October 11, 1911, the undersigned committee was appointed to consider and report upon the advisability of recommending constitutional amendments concerning methods of nominating and electing the officers of the Institute, and also to consider and report upon certain other features of general interest. Your committee has accordingly held a number of meetings, and as the result thereof begs to present the following report:

There has existed for some time a very definite conviction, at least in the central and western States, that, while the present system of nominating and electing officers has for the most part resulted in the choice of efficient and conscientious men, there has been little or no attempt to secure representatives in the Board of Directors of the members located at any considerable distance from headquarters. It is felt, moreover, that any tendency toward genuine representation on a geographical basis, such as might be expressed by the nominating ballots of large local groups, is most effectively blocked by the large constitutional powers exercised by the Board in nominating the Directors' Ticket; especially in view of the settled policy of the Board of selecting only those candidates whose affairs will permit frequent trips to the New York meetings.

As the first step in the study of the problem presented by this situation, the committee considered the geographical distribution of the present membership of the Board of Directors in its relation to the geographical distribution of the membership as a whole. For this purpose the membership was divided into seven (7) districts in such a way as to take into account both natural geographical units and reasonable uniformity of enrolment. These districts with their memberships as given in the 1912 Year Book, are as follows:

Districts	Membership
1. New York City and environs within a 50-mile radius...	1,389
2. New York State (excluding No. 1) and Canada......	942
3. New England (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut).....	607
4. Pennsylvania (Pennsylvania, New Jersey (excluding No. 1), Delaware, Maryland, District of Columbia)....	772
5. Central (Wisconsin, Michigan, Illinois, Indiana, Ohio)..................	1,095
6. Southern (Virginia, W. Virginia, N. Carolina, S. Carolina, Tennessee, Kentucky, Mississippi Alabama, Georgia, Florida and *Foreign Countries except Canada*)..........	1,011
7. Western (all States west of the Mississippi River)....	1,345
Total................	7,161

It is not contended that this particular division is the most suitable that could be devised, but it will suffice for present purposes.

The Board of Directors consists of 23 members, of whom two, the Secretary and the Treasurer, need not be considered in this analysis since they must necessarily be residents of New York City or its immediate vicinity. Of the remaining 21 members of this year's Board, there are eleven (11) from the New York City district, four (4) from the New York State district three (3) from the Central district and one (1) each from the New England, the Pennsylvania, and the Southern districts. Figured on a percentage basis, these data appear as shown in Table I, the districts being arranged in the order of magnitude of enrolment. The table brings out the facts so clearly that comment would be superfluous.

TABLE I. A. I. E. E.

District	Members	Officers	Per cent Members	Per cent Officers
New York City	1,389	11	19.4	52.5
Western	1,345	0	18.8	0.0
Central	1,095	3	15.3	14.3
Southern	1,011	1	14.1	4.76
New York State	942	4	13.1	19.0
Pennsylvania	772	1	10.8	4.76
New England	607	1	8.5	4.76
Total	7,161	21		

TABLE II. A. S. M. E.

District	Members	Officers	Per cent. Members	Per cent. Officers
New York City	996	7	25.1	33.3
Central	819	3	20.6	14.3
New England	618	2	15.5	9.5
Pennsylvania	574	6	14.4	28.6
Western	345	1	8.7	4.8
New York State	336	2	8.4	9.5
Southern	290	0	7.3	0.0
Total	3,978	21		

TABLE III. A. S. C. E.

District	Members	Officers	Per cent Members	Per cent Officers
New York City	1,308	7	22.4	25.0
Western	1,015	2	17.4	7.1
Northern	788	5	13.5	17.9
Southern	765	3	13.1	10.7
Central	721	4	12.3	14.3
Pennsylvania	682	4	11.7	14.3
New England	560	3	9.6	10.7
Total	5,839*	28		

* 19 members missing, addresses unknown.

In order to compare the conditions in the Institute with those in the American Society of Mechanical Engineers and in the American Society of Civil Engineers, Tables II and III have been prepared, the figures having been taken from the 1911 Year Books of these Societies. In the case of the A. S. M E. the districts have been arbitrarily taken to be the same as in the case of the Institute, but in the case of A. S. C. E. the districts are those defined by the Constitution of that Society.

The A. S. C. E. districts are defined as follows:

New York City.—New York City and environs within a radius of 50 miles.

New England.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut; Europe and Africa.

Northern.—New York, New Jersey, Michigan, Wisconsin, Minnesota, Canada, Alaska.

Pennsylvania.—Pennsylvania, Maryland, Delaware, District of Columbia.

Central.—Ohio, Indiana, Illinois, Iowa, Missouri.

Southern.—Virginia, W. Virginia, North and South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama Louisiana, Mississippi, Arkansas, Oklahoma, Texas, Mexico, Central America, South America, West Indies.

Western.—North and South Dakota, Nebraska, Kansas, Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, Washington, Oregon, Nevada, California; Hawaii, Asia, Australasia.

It will be observed from Table III that each group in the American Society of Civil Engineers has a representation in the governing body approximately proportional to its membership, except in the case of the Western district. This is due to the constitutional provision that a definite minimum number of officers shall be selected from each district. In the A. S. M. E. the distribution is not as uniform as in the A. S. C. E., but it is decidedly better than the A. I. E. E., which shows extreme irregularity.

The foregoing statistics, so far as the Institute is concerned, may fairly be said to indicate a situation that should not be allowed to continue. That it will continue unless some radical changes are made in the Constitution is a certainty, and all because of the fact that the Board will not nominate candidates who are unable or unwilling to meet the expense of frequent trips to New York City. In the A. S. M. E. there is a check upon the nominating power in that an independent ticket may be put forward upon the initiative of any group of fifty members, while in the A. S. C. E., as explained above, the principle of geographical representation is fully recognized. The situation in the Institute can be met in one of two ways, assuming, of course, that the members at large are not satisfied with existing conditions; either the Board of Directors must initiate constitutional amendments having in view a fair districting of the membership, with adequate representation from each district; or the various local Sections must put through such amendments by mutual agreement. But it should be borne in mind that something more is needed than a mere parceling out of the available offices; provision should at the same time be made to defray the traveling expenses of officers who may go to New York for the express purpose of attending meetings, or possibly the expenses of a certain portion of the entire number of meetings should be thus defrayed. This would obviate an objection that might otherwise arise, namely, that a failure to attend meetings on the part of the non-New York officers might still further concentrate power in the hands of the eastern representatives.

Your committee desires further to call attention to the anomalous conditions now existing with respect to the functions of the Sections Delegates. Under the Constitution the Delegates are the only representatives whose traveling expenses may be paid out of the Institute funds; they constitute at the same time the only body which may be said to voice the opinions of large bodies of non-New York members; and yet their functions are so hazy, and their organization so ill-defined, that their deliberations are practically valueless so far as definite results are concerned. It is perhaps needless to point out that such a body of men might exert a considerable influence if proper organization were effected; but inasmuch as under present regulations the Delegates can only be got together at the Annual Convention, at which time matters of policy cannot be officially taken up, their work is likely to continue to be ineffective unless, indeed, their meetings are protected from interference on the part of members who are not Delegates, and it be made mandatory for the Board to consider and report upon such recommendations or resolutions as the Delegates may formulate.

In order that these matters may receive the consideration which, in the judgment of the committee, they deserve, it is recommended:

1. That the St. Louis Section present a copy of this report to the Board of Directors for its consideration.

2. That a copy be sent to the Chairman of the Sections Committee with the suggestion that the matters herein contained be laid before the Sections Delegates at the forthcoming Annual Convention.

3. That copies be sent to the Chairman and Secretaries of all other Sections, with the request that the subject be fully discussed and the respective Delegates instructed as to the attitude to be taken in case the subject should be brought up at the Convention.

In conclusion, the committee recommends that the St. Louis Section urge the enactment of legislation which shall place the New York meetings upon the same footing as the meetings held in other cities, namely, that the meetings there be designated meeting of the New York Section, and that they be subject to the same regulations that obtain elsewhere.

(Signed) A. S. LANGSDORF,
Chairman
A. H. TIMMERMAN,
H. I. FINCH.

The following letter, although addressed to the members of the Sections Committee, is here published on account of its general interest to the membership.

Members of the Sections Committee,

Gentlemen: The purpose of this letter is to remind you of the coming annual convention of the Institute at Boston, June 24–28, and more specificially of the constitutional provision (Article IX, Section 70) for " an official delegate " from each Section, " who shall be the Chairman of that Section, or in his absence or inability to attend, an alternate delegate selected by the Section." The further constitutional provision that this " official delegate attending the annual convention may have his expenditures for transportation refunded by the Institute " should insure a full meeting of Section delegates at the coming Boston Convention.

Although the Constitution as above quoted thus provides for a board of Section delegates, it has not provided any specific duties for them. However, your Chairman has always proceeded on the assumption that the existence of this body presumed both responsibility and duties and it has been his constant endeavor both to define its powers and enlarge its influence. To that end the matters which have been discussed in our meetings have not been confined to Section affairs only; we have not hesitated to consider broad matters of Institute policy.

As indicated in my letter of February 5, 1912, to the Sections Committee, there were four matters which received particular attention from our committee last year. To my request contained in that letter for suggestions for new matters to be taken up by our committee, I have not yet received a single reply. I assume, therefore, that we can do no better than to take up again for discussion the same subjects as last year so far as discussion upon them applies under the present conditions.

These four subjects were:

1. The matter of an intermediate grade of membership.
2. Methods of electing Institute officers.
3. The appointment, versus the election, of the Secretary.
4. Method of securing cooperation of local Sections and other local engineering bodies.

1. In regard to the first of the above matters, you are undoubtedly aware that the amendment referred to in my letter of February 5 for an additional grade of membership, has been passed.

About 45 per cent of the membership voted on this amendment and about 83 per cent of those voting favored the amendment. This indicates a fairly unanimous sentiment in favor of the amendment; however, there has been discussion among some of our committee indicating objection to certain features that have been incorporated. I think it would be well for our committee to discuss this matter further and determine whether or not it is worth while to suggest to the Board of Directors any modifications to be submitted as further amendment in the coming year.

The one provision in the intermediate grade amendment that seems to have drawn more fire than any other is that fixing the dues. Whatever action our committee takes, please bear in mind that our time will be very much limited at the convention and that *constructive* criticism is the only kind that really counts; destructive criticism consumes time and usually leads nowhere. In order to conserve our time as far as possible, I would suggest that each committeeman be prepared in advance to express his opinion upon this matter of dues, to the end that this matter at least be disposed of with as little loss of time as possible. Whatever action we take upon a matter of this nature should take the form of a recommendation to the Board of Directors.

2. The method of electing Institute officers has been modified to some extent during the past year. As indicated in my letter of February 5, a distinct advance has been made in our method of election by providing for advance nominations. This worked fairly well during the past year but knowledge of the modification was not sufficiently disseminated at that time to make it work to the best advantage. I believe that this modification in our procedure of election deserves a thorough trial.

You will recall that our committee last year considered the advisability of making it a regular practise to nominate more than one candidate for each office each year, so that the election which now is usually only a confirmation of the Board's selection, would become a real contest. The opinion of our committee at that time was fairly evenly divided on this, but the upshot of our discussion was the modification in procedure above referred to. I would suggest that it would be wise to make a further trial of the modification referred to before taking further action on this particular matter.

Further, in connection with the matter of methods of election, I wish to call attention to a report of a committee of the St. Louis Section dated April 26, 1912. The Secretary of the Institute recently forwarded a copy of this report to each member of the committee.

There is much that is worthy of careful consideration in this St. Louis report. Whether it is wise for us to join with the St. Louis Section in recommending a modification in our Constitution similar to that they have outlined, is certainly a question which should properly come before us for discussion and action at our Boston meeting. In considering this St. Louis suggestion, it should be borne in mind that the Board of Directors of our Institute is a *working* body and it is essential that its members shall attend its meetings or else the influence of the members not attending is nil. That there is no deliberate intention of the Board to confine its membership to New York City engineers is evidenced by the last group of men elected as Vice-Presidents and Managers; of these seven men, only one hails from New York City. Milwaukee, Chicago, Boston, Albany, New Haven and Philadelphia were all represented by men elected at the last election. However, the Board has always felt that its members should attend at least a majority of its regular monthly meetings and what the St. Louis report says about that portion of the membership which is located at such a distance as not to be able to attend is strictly true. The payment of travelling expenses of Board members residing at a distance is only a partial answer to the problem, since a considerable part of our membership resides at so great a distance as to make attendance at Board meetings impossible in any event; for instance, Pacific Coast and European members.

Concerning what the St. Louis report says about the Section delegates, it is undoubtedly true that their functions are ill-defined, since they are not defined at all; whatever functions this body has are the results of its own actions. Also the fact that it can meet but once a year is undoubtedly a handicap. There is no reason, however, why both of these objections cannot be overcome. In the first place, there is no reason why definite functions for the "Board of Section Delegates" cannot be recognized by the Institute through the simple medium of a set of by-laws. In the second place, the proper function for such a "Board of Section Delegates" being admittedly of an *advisory* nature, there is no reason why the larger part of its deliberations cannot be carried on by mail. This, in conjunction with our regular meeting at the annual convention, ought to give a workable body. On the other hand, the functions of a body like the Board of Directors cannot be adequately carried out by the use of the mails.

As a substitute, therefore, for the

suggestion offered by the St. Louis Section, one which will require a far reaching modification in our Constitution and could, therefore, not possibly go into effect for at least a year, I would offer the following plan,—one which requires no modification of the Constitution and can be adopted by the Board of Directors in the shape of by-laws and could, therefore, go into effect almost immediately:

1. The existence and functions of the "Board of Section Delegates" as defined in Article IX, Section 70, of the Constitution should be formally recognized in the by-laws governing the procedure of the Institute.

2. That these by-laws shall among other things make it mandatory upon the Board of Directors to take up for immediate consideration any matter of Institute policy that has received the approval of one-half of the Section Delegates, approval by mail being recognized as valid.

3. That any Section may initiate any matter of Institute policy and it shall be mandatory upon the Chairman of the Sections Committee upon request of that Section to communicate such matter to the other Sections, with request for prompt action by them thereon. Upon receipt of proper action from one-half the Sections he shall present the matter to the Board of Directors for their consideration as indicated under (2) above.

I would request that the Section delegates come prepared to take some definite action upon the above.

4. The matter of appointment, versus election, of our Secretary, seems to have been settled thoroughly at the last election. As you know, the amendment providing for the Secretary's appointment came up for the third time at our last election. About 43 per cent of the membership voted on this amendment, of whom about 92 per cent were in favor. This seems to be so definite in answer to this question that further discussion will probably be unnecessary. Unless, therefore, there is some strong feeling on the part of our delegates, I would suggest that this matter be not brought up, in order to have more time for the other important matters before us.

5. The question of securing proper cooperation between our local Sections and other local engineering bodies is one which is always before our Sections. As indicated in my letter of February 5, the St. Louis Section has a formal working arrangement between our local Section and the other engineering bodies in St. Louis; the Milwaukee Section has a somewhat similar arrangement. The Washington Section is considering an affiliation upon almost the same plan. The question of a similar affiliation in the Pittsburgh district is now before the engineering bodies of Pittsburgh, and your Chairman has been appointed as the chairman of a committee to bring about some such affiliation. Nothing definite has yet been done in Pittsburgh and your Chairman is looking for all the information on this matter which he can obtain. Your Chairman's interest in this question is, therefore, personal as well as general, and he hopes for a full discussion of this important matter.

As has been indicated before, the principle which should govern the work of all the engineering bodies in a given city is that of cooperation and not antagonism. Nothing can be gained by antagonism, while the influence of all the engineering bodies would be augmented by proper cooperation. The case before us is simply a question of the particular machinery by which cooperation can best be secured.

Your Chairman is pleased to observe that much interest has been created among the Sections during the past year by the activities of President Dunn during his year in office. Among other Sections, St. Louis, Los Angeles, San Francisco, Portland, Pittsburgh, Philadelphia, Schenectady, Ithaca, Boston and Lynn have all had the influence of personal contact with our President during the past year; this has done much to stimulate active interest among the Sections.

Honorary Secretary Pope has also been active in creating Section activities and has visited may of the Sections, practically extending from Vancouver on the west to Boston on the east. Our Sections are certainly fortunate in receiving the attention and assistance of these two men.

Your Chairman is unable to announce any exact meeting times of our committee, but these will be announced to the delegates as soon as they arrive at Boston. We should strive to have at least three sessions; one for the matter of an intermediate grade of membership; one for the matter of Institute elections and the suggested policy growing out of this question; and one for the matter of cooperation of Sections with other engineering bodies.

I would request that the official Section delegates register with the Secretary as such as soon as they arrive in Boston.

Very truly yours,
P. M. Lincoln,
Chairman
Pittsburgh, Pa., June 5, 1912.

To the membership of the A. I. E. E.

I have read with interest a communication of the St. Louis Section under date of April 26, submitted to the Board of Directors on May 21, urging a modification in the method of electing the Institute Directors with a view of securing what is termed a better geographical representation.

This is a matter which has been discussed from time to time intermittently over a long period but I do not think it is one which is generally understood by the membership at large, and as it is extremely important, if the subject is to be discussed at the Boston Convention, that participants should have a reasonable foreknowledge of the facts, may I take the liberty of outlining them from the point of view of one who has served for a number of years on the Board of Directors?

The position of the St. Louis Section committee is a most natural one. I do not think there will be found any one who has the interests of the Institute at heart who will seriously oppose the view that the managing body of the Institute should be as thoroughly representative of the membership at large as it is possible for it to be. Certainly I have never seen manifested on the part of those living near New York the slightest desire to exclude from the Institute councils the more remote members or to perpetuate a control of the national body by a small geographical section.

Starting with this general agreement of view point, we come up against not the theoretical but the practical question of how the Institute affairs are to be handled. That in the past they have been handled with most excellent results by a Board of Directors meeting monthly, the enormous growth and success of the Institute is ample proof. In addition to the monthly meetings a very large number of committee meetings participated in by the individual members of the board have occurred between the regular meetings. So long as this method of management continues it is absolutely essential that there should be a sufficient number of the Board of Directors within reasonable reach of headquarters to properly perform the duties devolving upon them. I can testify without fear of contradiction that during the five years I had the pleasure of serving on the Board of Directors, even though a large majority of the men lived either in or near New York City, it was frequently embarrassing and inconvenient to man properly the various committees and get the necessary work done because even a minor part of the board was not geographically available.

If you carry the St. Louis Section's plan to its logical conclusion, you must have a Board of Directors composed of men from Atlanta, St. Louis, Chicago, San Francisco, Denver, Boston, Pittsburgh, Schenectady and New York.

That such a body of men would be regular in their attendance at monthly meetings at any place, much less at the daily and weekly committee meetings, is on its face impossible. Such a plan at once would make necessary an entirely different method of managing the Institute's affairs. In my judgment the St. Louis Section would be less likely to have its views on current matters favorably considered by the Board of Directors from time to time if it had a St. Louis representative on that board who was unable to attend the meetings and really do committee work than under the conditions which have prevailed in the past. That is to say, while nominally having a representation, their actual representation would approach zero. The more distant Sections cannot expect, if the St. Louis plan is carried into effect, that a one-eighth representation of New York members will continue to attend the Directors' meetings and do seven-eighths of the work.

It is suggested that an allowance should be made for traveling expenses of the more distant members. This solution ignores the matter of time. The men we want to direct Institute affairs are men whose time is valuable. In the past these men have given an hour or two now and then and a half day once a month to Institute affairs. Does any one think these same men would give from two days to a week every month for the same purpose? Further, up to the present time all of those who have accepted directorships and lived outside of New York have paid their own expenses to the meetings. An examination of the Institute's finances will show that the growth of expenses has fully kept pace with the growth of revenues, and if we are to assume any such burden as would follow on the adoption of the St. Louis plan, we must face the necessity of a material increase in our dues or a radical reduction in our activities in other directions.

These are the practical facts from which there is no escape. In my view the Institute should be slow to revolutionize methods which have been so eminently successful in the past and I believe that those who have been loudest in demanding a change would be the first to oppose it if they themselves had been through the mill, knew the vast amount of work and time spent by the Directors and had seen the difficulty of getting men to do it.

Yours very truly,

CALVERT TOWNLEY

A. I. E. E. Annual Meeting, May 21, 1912

The Annual Meeting of the A. I. E. E. was held at the Engineers Building, New York, Tuesday, May 21, 1912.

President Dunn called the meeting to order at 8:20 p.m. and called upon Secretary Hutchinson to present in abstract the report of the Board of Directors. The complete report will be printed in the July PROCEEDINGS.

On motion the Directors' report was adopted and ordered placed on file.

The next order of business was the announcement of the result of the elections. The report of the Tellers was delivered to President Dunn, who announced the election of officers, and the carrying of the Constitutional amendments for the appointment of the Secretary, and the creation of an additional grade of membership. Of the vote on the Secretary amendment 92 per cent was affirmative and on the additional grade 83 per per cent. The complete tellers' reports of these votes are published on another page.

The ceremonies of presenting a bust of Joseph Henry to the Associazione Elettrotecnica Italiana as an appreciation of the gift some years ago of the bust of Galileo Ferraris and in recognition of the many courtesies extended to the officers and members of the Institute at the Turin Congress, were opened by President Dunn, who spoke of the friendly relations which have always existed between the Italian society and the Institute. The committee felt that American electrical engineers and scientists could not choose a more fitting gift than the bust of Joseph Henry for this presentation. Fortunately there is in existence, by the hand of the distinguished artist Herbert Adams, a heroic statue of Henry, in Washington, and we are indebted for the cooperation of Mr. Adams in securing a replica of the bust of this statue.

President Dunn introduced Mr. Philip Torchio, who had been appointed its delegate by the Associazione Elettrotecnica Italiana to receive the Institute's gift.

Mr. Torchio, in accepting it in the name of the Italian society, made some brief remarks expressing the hearty appreciation of the Italian society and the reciprocal feelings of kindness and regard existing between it and the Institute.

At the close of Mr. Torchio's address, President Dunn introduced Dr. Charles A. Doremus, who announced the presentation to the Institute of Professor Henry's astatic galvanometer by Dr. Henry E. Waite, and of one of the original Henry induction coils by the family of Prof. R. Ogden Doremus. He said he felt that the present meeting was a very fitting and proper occasion on which to turn these instruments over to the Institute. Accompanying the gift of these articles is a letter from Dr. Charles A. Doremus, as follows:

Mr. Gano Dunn,
President of the American Institute of Electrical Engineers,

My dear Sir:—When Prof. Joseph Henry's laboratory at the Smithsonian Institution was dismantled some of the apparatus was bought by Mr. William Green, electrician of the Institution. An astatic galvanometer, made by Ruhmkorff, of Paris, Mr. Green gave to Dr. Henry E. Waite, of New York, who now presents it to the Institute with his compliments.

In his researches on "self-induction" Professor Henry made use of coils of insulated copper wire and of broad, thick, insulated copper ribbons. One of these Mr. Green gave to Dr. Waite, who presented it to Prof. R. Ogden Doremus, who used it for many years in demonstrating Henry's discoveries to his classes.

Professor Doremus' family have long thought that this historical relic should belong to the Institute and it seemed to them particularly appropriate to give it this evening when we are met to honor Henry and when you, Sir, a pupil of Professor Doremus, of whose achievements he was very proud, and for whom he had a deep personal affection, are President.

May this evidence of the simple means used by Henry to attain wide-reaching results be an inspiration to us all.

Yours very sincerely,
Charles A. Doremus.

These interesting and valuable gifts to the Institute were fittingly acknowledged by President Dunn.

The address which had been announced, by Mr. John C. Barclay, on the subject of "Henry as the Inventor of the Telegraph," was read by title as Mr. Barclay was unavoidably absent from the meeting. Mr. Barclay's paper will appear in the Proceedings.

The ceremonies of the evening were concluded by a masterly address by Dr. Michael I. Pupin on "The Debt We Owe to Henry as a Scientist." Lack of space prevents the publication of Dr. Pupin's address here, but it will become a part of the permanent records of the Institute.

At the close of Dr. Pupin's address a particularly appreciative vote of thanks was unanimously given. A vote of thanks was also extended to the sculptor, Herbert Adams, for the work which he so graciously did for the Institute in making the presentation of the bust of Henry possible.

After the close of the ceremonies the meeting adjourned to the Institute offices on the tenth floor, where the last and one of the best attended and most successful smokers and social reunions of the season was held.

Joubert Memorial

The committee appointed by President Dunn in March to collect funds for the Joubert Memorial recently held a meeting for the purpose of formulating a plan for carrying on its work. The chairman of the committee, Mr. C. O. Mailloux, during his recent visit to Paris attended a meeting of the

French Committee, which has been formed for the same purpose, and he also conferred while in London with the President of the Institution of Electrical Engineers, who has promised to take up the matter and appoint a similar committee. Similar committees will also be formed in Italy, Belgium and other countries. The American Committee will be considerably enlarged, and its appeal to members for subscriptions will be issued simultaneously with similar appeals in the other countries.

New Grades of Membership

As stated elsewhere in this issue, the constitutional amendments providing for three grades of membership, in place of the present two grades, were adopted by vote of the membership at the annual meeting of the Institute held May 21, 1912. These amendments go into effect June 21, 1912. The provisions of the amended Constitution providing for the transfer of present Associates and Members to the grades of Member and Fellow respectively, are as follows:

SPECIAL SECTION. Any person who shall be a Member at the time of this group of amendments is adopted, shall, on written request to the Secretary prior to May 1, 1913, without the payment of the transfer fee, or increase of life membership fee, have the right to become a Fellow, provided he refers to at least five Fellows or Members who, upon inquiry, shall certify that he meets the requirements of the grade of Fellow, as herein defined.

Any person who shall be an Associate at the time this group of amendments is adopted shall, on written request to the Secretary prior to May 1, 1913, without the payment of the transfer fee, or increase of life membership fee, have the right to become a Member, provided he refers to four Fellows or Members who, upon inquiry, shall certify that he meets the requirements of the grade of Member, as herein defined.

The dues of Members and Associates transferred under the provisions of this special section shall not be increased until May 1, 1913.

The by-laws relating to these transfers as adopted at the meeting of the Board of Directors held May 21, 1912, read as follows:

SPECIAL SECTION. Any person who was a Member or Associate in good standing on May 21, 1912, may apply for transfer to the grade of Fellow or Member respectively (in accordance with the special section of Article II of the Constitution, adopted May 21, 1912), under the following conditions:

a. Applications shall be made on forms prescribed by the Board of Directors; these forms will be supplied by mail or otherwise upon application to Institute headquarters.

b. Applications must be submitted to the Secretary prior to May 1st, 1913.

c. Applications shall embody a statement of the age, period of practise, and present occupation of the applicant and shall state under which one or more of clauses " a, b, c, d " of Sections 4 or 5, Article II, of the Constitution the application is made.

d. Applicants shall refer to the number of references specified in the special section, Article II of the Constitution, each of whom shall be invited by the Secretary to certify upon a prescribed form that the applicant meets the requirements of the grade desired, as defined in Article II of the Constitution, which requirements shall be printed on the form. Upon receipt of the required number of certifications in proper form, the Board of Examiners shall approve the application for publication of the names of the applicant and his certifiers in the PROCEEDINGS; and, not less than twenty days after publication, the Board of Directors shall act upon the application.

e. Should an applicant for transfer to the grade of Member or Fellow certify that he is not personally known to the required number of members of the respective grades as specified in the Special Section of Article II of the

Constitution, the Board of Examiners may accept for the deficiency other references, preferably professional engineers who are members of leading American or foreign engineering societies.

f. The names of all applicants transferred by the Board of Directors in accordance with this special section shall be published in the PROCEEDINGS.

As indicated in the By-laws, all applications must be made on special forms which will be ready for distribution about June 15, and will be supplied to any Associate or Member promptly upon application to the Secretary at Institute headquarters.

Erroneous Report of Action of Philadelphia Section

In a notice on page 196, Section I, of the May PROCEEDINGS, through a misunderstanding the name of the Philadelphia Section was included among those which had indorsed the amendment to the Constitution providing for an additional grade of membership. It is desired to take this first opportunity to correct the error, and to apologize to the Philadelphia Section for the mistake.

Pacific Coast Meeting, Portland, Ore., April 16-20, 1912

The 271st meeting of the American Institute of Electrical Engineers convened at 11:00 a.m., April 16, 1912, at Portland, Oregon, with Mr. F. D. Weber, chairman of the Portland Section, in the chair.

Mr. Weber called upon Mr. S. G. McMeen, who delivered the address of welcome. President Gano Dunn then replied in a short address in which he called the particular attention of the members of the Institute to the proposed amendments to the Constitution. The meeting then adjourned until 1:30 p.m., when the first technical session was held. President Dunn presided.

The schedule of papers presented was as follows:

Tuesday Afternoon, April 16th:

Arc vs. Tungsten Lighting for Small Towns, by C. E. Stevens. This paper was presented on behalf of Mr. Stevens by Mr. A. A. Miller of Seattle, Wash.

Irrigation in the Spokane Valley, by L. J. Corbett, University of Idaho, Moscow, Idaho.

Wednesday Morning, April 17th:

Automatic Private Branch Exchange Development in San Francisco, by Gerald Deakin, San Francisco, Cal.

The Application of Automatic Selecting Devices to Telephone Multiple Switchboards, by A. H. Dyson, Chicago, Ill.

Design of Telephone Pole Lines for Conditions West of the Rocky Mountains, by A. H. Griswold, San Francisco, Cal.

Thursday Morning, April 18th:

Operation of Two Alternating-Current Stations through Parallel Circuits and the Distribution of the Load and Wattless Current between Them, by J. W. Welsh, Pittsburgh, Pa.

Plant Efficiency, by J. D. Ross, Seattle, Wash.

Practical Joint Pole Construction, by J. E. Macdonald, Los Angeles, Cal.

Thursday Afternoon, April 18th:

Principles to be Considered in Selecting a Water Wheel Unit, by O. B. Coldwell, Portland, Ore.

Alternating-Current Systems of Underground Distribution, by S. J. Lisberger and C. J. Wilson, San Francisco, Cal.

An Underground System and a Few Developments, by S. B. Clark, Portland, Ore.

The men presiding at the various technical sessions, in addition to President Dunn, were S. G. McMeen, Portland, Ore., A. A. Miller, Seattle, Wash., and P. M. Downing, San Francisco, Cal.

Entertainment:

The principal entertainment features in connection with the meeting were as follows:

Tuesday evening, April 16th, at the Multnomah Hotel, an informal dinner was held at which 124 visitors and local people were present. At the conclusion of the dinner Mr. Weber acted as toastmaster and called upon a number for impromptu speeches, among whom were President Gano Dunn, Honorary Secretary R.W. Pope, Messrs. A. H. Babcock, S. G. McMeen, B. S. Josselyn, J. E. Macdonald, W. W. Briggs, and J. E. Davidson.

On Wednesday afternoon, April 17th, there was no technical session and a party of about 100 visitors and friends were taken on a steamer trip through the harbor, stopping at Station "L", the new steam plant of the Portland Railway, Light and Power Company, where they were shown through the station. From this point the steamer went up the Willamette River to Oregon City, where the visitors had a very good view of the Willamette Falls and the manufacturing plants located at this point.

Thursday afternoon the final technical session was held and in the evening, in the ballroom of the Multnomah Hotel, the members and guests assembled to hear a talk by Mr. A. H. Babcock of the Southern Pacific Company, regarding the 1200-volt direct-current electrification of the Southern Pacific Company's local lines leading out of Oakland, Cal. Mr. Babcock's talk was very interesting and instructive and was illustrated by numerous lantern slides.

At this point in the meeting, the following resolutions were presented, and passed unanimously:

Whereas the Pacific Coast meeting of the American Institute of Electrical Engineers held in the City of Portland has been a most successful one, and is now drawing to a close; and,

Whereas the success of this meeting has been due to the presence of the President, Honorary Secretary and to the active efforts and interest shown by the convention committee and local membership, ably assisted by the ladies of Portland; be it therefore

Resolved, that the thanks of the visiting members and ladies be extended to President Dunn, to Secretary Pope, to the members of the convention committee, to the members of the Portland Section and to the ladies of Portland; and be it therefore further

Resolved, that this resolution form a part of the record of this meeting and be placed in the permanent files of the Portland Section of the American Institute of Electrical Engineers.

Portland, Ore., April 18, 1912.

Following the talk, President Dunn made a few remarks and then Mr. O. B. Coldwell, on behalf of the Portland Section, presented President Dunn with a silver loving cup as a token of the good feelings and wishes of the members of the local Section.

On Friday, April 19th, an all-day trolley trip was planned, to visit the two hydroelectric plants of the Portland Railway, Light and Power Company located on the Clackamas River and the hydroelectric plant located on the Bull Run River. A special train carrying about 160 members of the Institute, visitors and local people left the city at 9:15 a.m. The first plant visited was the River Mill plant, after which luncheon was served at the Estacada Hotel. The party then visited the Cazadero plant. At this point one of the cars unfortunately was derailed, causing a delay of about two hours, so that upon a vote of the members of the party, the trip to the Bull Run development was given up. Arrangement was made, however, so that any of the party who desired could visit the Bull Run development the following day, and about twenty took advantage of it.

Other members, who did not care to visit the Bull Run development, made trips on Saturday to various telephone plants in Portland, and the substations of the Portland Railway, Light and Power Company.

For the visiting ladies a number of special entertainments were provided:

On Tuesday afternoon a special car took the ladies to Willamette Heights and to Council Crest—the scenic sections of the city. On Wednesday afternoon a luncheon was served at the Multnomah Hotel. On Thursday afternoon an automobile trip round the city was provided, and in the evening there was a theater party at the Heilig Theater.

In addition to the above entertainment the ladies enjoyed the trips to Oregon City and to the hydroelectric plants, provided for the members.

The entertainment committee which had in charge the entertainment features consisted of O. B. Coldwell, of the Portland Railway, Light and Power Company, chairman; R. F. Monges, of the General Electric Company; C. B. Smith, of the Pacific Power and Light Company, and J. A. Rockwood, of the Portland Railway, Light and Power Company.

Assisting this committee was a ladies' entertainment committee, the members of which were Mrs. F. S. Turner, chairman; Mrs. A. S. Moody, Mrs. O. B. Coldwell, Mrs. R. F. Monges, Mrs. A. E. West and Mrs. E. S. Taylor.

Registration:

According to the registration cards the total attendance at the meeting was as follows:

Visiting members and their guests	113
Local members and their guests	98
Visiting ladies	40
Total	251

This list is fairly complete, as the registration committee was quite successful in securing registration from nearly everyone who attended the meeting or the entertainment features in connection therewith. From the registration cards the registration committee had printed for distribution on Thursday, April 18th, leaflets giving the names and addresses of all those in attendance. As this first leaflet was not complete and accurate, a second and revised list was printed and brought up to date on Saturday, April 20th, and copies were mailed to all out-of-town members who were in attendance.

Pittsburgh Meeting, April 25-27, 1912

The two hundred and seventy-second meeting of the Institute, at Pittsburgh, held under the auspices of the Industrial Power Committee in conjunction with the Association of Iron and Steel Electrical Engineers, was called to order in the Fort Pitt Hotel, at 11:15 a.m. April 25, by Mr. K. C. Randall, chairman of the Pittsburgh Section of the A. I. E. E. Mr. Randall introduced President Gano Dunn.

The first paper was presented by Mr. C. J. Fechheimer, on *Self-starting Synchronous Motors*. Owing to the long and important discussion of this paper it was found advisable to postpone the second paper scheduled for the morning session until afternoon.

The afternoon session was called to order at 2 o'clock by President Dunn and the following papers presented, and discussed:

Direct-Current and Alternating-Current Mill Motors for Auxiliary Drives, by Brent Wiley.

The Electrical Braking of Induction Motors, by H. C. Specht.

Advantages of Automatic Control in Steel Plant Operation, by Stewart C. Coey.

Motor and Control Equipment of Electrically Operated Valves, by H. M. Gassman.

At 6:30 p.m. approximately 100 delegates sat down to an informal dinner in the English Room of the hotel. After the tables were cleared informal remarks were made by President Dunn, Dr. F. B. Crocker, Professor C. F. Scott, Dr. C. P. Steinmetz, and several others.

The Friday morning session was called to order at 10:15 a. m. by Mr. Randall and the following papers presented:

Electrification of a Reversing Mill of the Algoma Steel Company, by Bradley T. McC rmick.

Operation of a Large Electrically Driven Reversing Rolling Mill, by Wilfred Sykes.

At 1:15 p.m. approximately 80 of of those attending the meeting boarded a special car provided by Mr. P. N. Jones, general superintendent of the Pittsburgh Railways, and were carried to the Homestead Works of the Carnegie Steel Company where, under the efficient guidance of Messrs. C. A. Menk, electrical superintendent, Charles Proudfoot, assistant electrical superintendent, and a corps of guides, an instructive tour was made through the largest steel mill in the country.

At 3:15 p.m. the delegates boarded the private car and were carried to the Westinghouse Electric and Manufacturing Company's plant at East Pittsburgh, where an enjoyable hour was spent looking over the plant. From there the delegates were taken, in automobiles provided by members of the Westinghouse Electric and Manufacturing Company and the Westinghouse Machine Company staff, for a ride through the parks and residential district of Pittsburgh to the Fort Pitt Hotel. Friday evening was devoted to a theatre party.

Saturday morning the session was called to order at 10 o'clock by Mr. Randall and the following papers presented:

Electrical Control of a Large Mine Hoist, by Mr. H. W. Cheney.

Notes on the Use of Alternating Current in Unloading Coal, by Messrs. W. N. Ryerson and J. B. Crane.

Does it Pay the Average Coal Mine to Purchase Central Station Power? by Graham Bright.

The meeting was officially adjourned at 1:30 p.m. Saturday by Mr. Randall. The total attendance registered at the meeting was 265.

Schenectady Meeting, May 17, 1912

The 273rd meeting of the American Institute of Electrical Engineers was held under the auspices of the Schenectady Section at the Mohawk Golf Club, Schenectady, May 17, 1912.

The morning session was opened at about 9:30 o'clock by Mr. E. B. Merriam, Section chairman, who, after a few brief remarks, introduced Rev. George R. Lunn, mayor of the city of Schenectady. Mayor Lunn delivered a cordial address of welcome to the members and guests and paid a glowing tribute to the engineering profession, predicting for it a very bright future.

Dr. Charles P. Steinmetz, past-president of the Institute, replied to the welcome, after which the Section chairman introduced Mr. Gano Dunn, president of the A. I. E. E., who assumed the chair.

The following technical papers were then presented in abstract by the several authors:

Compression Chamber Lightning Arrester and Protection of Distribution Circuits, by E. E. F. Creighton and F. R. Shavor.

Human Accuracy: the Multi-Recorder for Lightning Phenomena and Switching, by E. E. F. Creighton, H. E. Nichols and P. E. Hosegood.

Study of Protection and Protective Apparatus for Electrical Railways, by E. E. F. Creighton, F. R. Shavor and R. P. Clark.

Propagation of Impulses over a Transmission Line, by J. H. Cunningham and C. M. Davis.

Some Mechanical Considerations of Transmission Systems, by T. A. Worcester.

Electrical Characteristics of Suspension Insulators, by F. W. Peek, Jr.

The discussion was opened by Mr. E. M. Hewlett and was continued by Messrs. P. M. Lincoln, Wm. McClellan, C. E. Magnusson and Dr. Charles P. Steinmetz and was closed by Messrs. R. P. Clark, T. A. Worcester and F. W. Peek, Jr.

Following this discussion, a paper on *Frequency* by Mr. D. B. Rushmore was presented in abstract, in the absence of the author, by Mr. E. A. Lof. Professor Samuel Sheldon opened the discussion and was followed by Messrs. J. J. Frank, B. G. Lamme, H. R. Summerhayes, C. F. Scott and N. J. Neal, Mr. Lof closing.

At the conclusion of the morning session a group photograph of the delegates was taken.

A buffet luncheon was served, following which three large parties left for inspection trips to the Schenectady Works of the General Electric and American Locomotive Companies and the electrical water works system of the city of Schenectady.

Those who did not desire to go on these trips took part in a golf tournament for which two prizes were offered.

During the afternoon, a meeting of the Standards Committee of the Institute was held at the Golf Club. Various suggestions for improving the Standardization Rules of the A. I. E. E. were discussed.

A meeting of the Educational Committee of the A. I. E. E. was also held at which were discussed many matters of interest.

At 6:00 p.m. a Dutch Dinner was served at the Club House, 100 members and guests attending. Following the dinner, with Chairman Merriam acting as toastmaster, Messrs. C. F. Scott, P. M. Lincoln, W. B. Potter, J. P. Jackson and President Dunn spoke on many topics of interest.

The evening session was opened at about 8:15 o'clock with President Dunn in the chair. The first paper, ***Ozone: Its Properties and Commercial Production***, was presented in abstract by Dr. M. W. Franklin. It was discussed by Messrs. C. E. Skinner, M. O. Troy, J. L. Woodbridge and W. L. R. Emmet, the discussion being closed by Dr. Franklin.

Following this, Mr. C. E. Eveleth presented an abstract of his paper on *The Electric Traction Situation in Europe*, which was discussed by Messrs. B. G. Lamme, M. W. Alexanderson, C. F. Scott and W. B. Potter.

Freight Train Tests on an Electric Interurban Railway was then presented in abstract by S. T. Dodd. Professor C. F. Scott discussed the paper and Mr. Dodd answered the questions raised.

At the close of the evening session, an informal smoker and social gathering was held in the Club rooms, marking the close of a very successful meeting.

The registration numbered over 354 members and guests.

The following societies had been especially invited to attend the meeting: the Society of Engineers of Eastern New York, Empire State Gas and Electric Association, Schenectady Section of National Electric Light Association, and the Pittsburgh, Lynn and Pittsfield Sections of the A. I. E. E.

Report of the Committee of Tellers on Election of Officers

To the President of the
American Institute of Electrical Engineers,

DEAR SIR:—This committee has carefully canvassed the ballots cast for officers for the year 1912–1913. The result is as follows:

Total number of ballot envelopes received	2483
Rejected on account of bearing no identifying name on outer envelope, according to Article VI, Section 33, of the Constitution	42
Rejected on account of voter being in arrears for dues on May 1, 1912, as provided in the Constitution and By-laws	69
Rejected on account of ballot not being enclosed in inner envelope, or on account of inner envelope bearing an identifying name, according to Article VI, Section 33, of the Constitution	49
Rejected on account of having reached the Secretary's office after May 1st, according to Article VI, Section 33, of the Constitution	26
Leaving as valid ballots	2297

These 2297 valid ballots were counted, and the result is shown below:

For President	
Ralph D. Mershon	2284
Scattering and Blank	13
For Vice-Presidents	
William S. Murray	2256
Arthur W. Berresford	2242
S. D. Sprong	1916
Harry E. Clifford	166
Henry H. Norris	267
Scattering and Blank	44
For Managers	
Comfort A. Adams	2263
William B. Jackson	2213
William McClellan	1913
J. Franklin Stevens	2050
Ernst J. Berg	260
Frederick Bedell	169
Lewis T. Robinson	124
S. M. Kintner	84
Scattering and Blank	112
For Treasurer	
G. A. Hamilton	2294
Scattering and Blank	3
For Secretary	
F. L. Hutchinson	2291
Scattering and Blank	6

Respectfully submitted,
H. W. FLASHMAN, *Chairman.*
WM. C. YATES.
FREDERICK BORCH
BENJ. K. BOYCE.
ROBERT MORRIS.
May 9, 1912. *Committee of Tellers.*

Report of Committee of Tellers on Constitutional Amendments Relating to an Additional Grade of Membership

To the Board of Directors,
American Institute of Electrical Engineers,

GENTLEMEN:—This committee has canvassed the ballots cast on the constitutional amendments relating to an additional grade of membership, submitted to the membership in a circular letter dated March 21, 1912. The result is as follows:

Total number of ballot envelopes received		4068
Of these the following were rejected in accordance with the Constitution and By-laws for the reasons given below		
No name on envelope	177	
In arrears for last year's dues	124	
Received after May 14	118	
Resigned after voting	9	
Blank ballots	268	
Total rejected		696
Leaving as valid ballots		3372

These valid ballots were counted and the result is as follows:

In favor of the adoption of the proposed amendment	2800
Against the adoption of the proposed amendment	572
Total vote	3372

The vote in favor of the amendment was therefore 92 per cent of the total vote.

(The total membership of the Institute upon May 14, 1912, which was the last day upon which ballots could be received, was 7433.)

The total vote was therefore 44 per cent of the membership.

Respectfully submitted,
H. W. FLASHMAN, *Chairman.*
FREDERICK BORCH.
BENJ. K. BOYCE.
ROBERT MORRIS.
WM. C. YATES.
Committee of Tellers.

May 20, 1912.

Report of the Committee of Tellers on Constitutional Amendments Relating to Election of the Secretary

To the Board of Directors,
American Institute of Electrical Engineers,

GENTLEMEN:—This committee has canvassed the ballots cast on the constitutional amendments relating to the election of the Secretary, submitted to the membership in a circular letter dated March 21, 1912. The result is as follows:

Total number of ballot envelopes received		4068
Of these the following were rejected in accordance with the Constitution and By-laws for the reasons given below		
No name on envelope	177	
In arrears for last year's dues	124	
Received after May 14th	118	
Resigned after voting	9	
Blank ballots	326	
Total rejected		754
Leaving valid ballots		3314

These valid ballots were counted and the result is as follows:

In favor of the adoption of the proposed amendment	3034
Against the adoption of the proposed amendment	280
Total vote	3314

The vote in favor of the amendments was therefore 83 per cent of the total vote.

(The total membership of the Institute upon May 14, 1912, the last day upon which ballots could be received, was 7433.)

The total vote was therefore 45 per cent of the total membership.

Respectfully submitted,
H. W. FLASHMAN, *Chairman.*
FREDERICK BORCH.
ROBERT MORRIS.
BENJ. K. BOYCE.
WM. C. YATES.
Committee of Tellers.

May 20, 1912.

University of Nebraska Vacancy

The University of Nebraska desires to obtain a head for its Department of Electrical Engineering at a salary of about twenty-five hundred dollars per year. It is the intention to strengthen the department and bring it up to a high standard in respect to equipment, quarters, and instructional force.

Further information may be obtained by addressing Professor O. V. P. Stout, Dean of the College of Engineering, University of Nebraska, Lincoln, Nebraska.

President Dunn's Dinner

On the invitation of President Dunn, the Board of Directors of the Institute and the chairmen of the various committees attended a dinner at the University Club on the evening of May 20, 1912, to meet the Past-Presidents. The following were present:

Prof. Comfort A. Adams, Mr. A. W. Berresford, Mr. H. W. Buck, Mr. W. G. Carlton, Dr. Louis Duncan, Prof. A. F. Ganz. Mr. F. L. Hutchinson, Mr. Carl Hering, Prof. D. C. Jackson, Mr. W. B. Jackson, Prof. John Price Jackson, Dr. A. E. Kennelly, Mr. John W. Lieb, Jr., Mr. P. M. Lincoln, Mr. H. W.Flashman, Mr. T. C. Martin, Mr. William McClellan, Mr. Farley Osgood, Mr. Ralph W. Pope, Mr. W. H. Powell, Mr. W. S. Rugg, Mr. D. B. Rushmore, Mr. Lewis B. Stillwell, Mr. C. E. Scribner, Mr. S. D. Sprong, Mr. N. W. Storer, Mr. J. Franklin Stevens, Mr. F. J. Sprague, Prof. Charles F. Scott, Dr. Samuel Sheldon, Mr. Charles W. Stone, Prof. George F. Sever, Mr. P. H. Thomas, Mr. Charles A. Terry, Dr. Edward Weston, Mr. W. D. Weaver.

All were seated at the one table, which was charmingly decorated with lilacs and carnations. Before entering the banquet hall opportunity was afforded for every one to meet those whom he did not already know.

After the delicious dinner was served Mr. Dunn stated that his purpose in having the Past-Presidents meet the Board of Directors and committee men was that the traditions of the Institute might be handed down and matters vital to the welfare of the Institute discussed. He expressed his deep appreciation and thanks for the generous cooperation of all those who had given their time and effort for the advancement of the Institute during the past year, and called upon a number of his guests to speak as to the past, the present and also the future problems which the Institute will have to meet.

Mr. Berresford, chairman of the Finance Committee, spoke of the financial problems, referring briefly to the new conditions which the adoption of the pending amendments might entail.

Mr. Lincoln set forth the thought of the Sections that the New York monthly meeting might more properly be a New York Section meeting.

Mr. Pope spoke as to the vital interest which the members at large have in the affairs and conduct of the Institute as explained in the desire for more meetings in various parts of the country.

Mr. Stillwell brought out that a much larger number of papers had been presented this year than ever in the history of the Institute. He rehearsed the most important problems facing the Institute and recommended a midwinter meeting in New York, the regular monthly meetings becoming Section meetings, so that more general topics may be brought up for discussion and without the presentation of a formal paper.

Dr. Sheldon pointed out the successful operation of the Joint Library and the increased activities developing from the Library facilities.

Mr. Thomas set forth the theory of the amendments as to change in grade of membership.

Mr. Terry clearly showed that the legal difficulties in Institute operations can be readily handled so that its interests will be properly conserved.

Others spoke on other topics of vital interest to the Institute, but it is not necessary to name them all. The intense feeling of loyal service and endeavor for the furtherance of the progressive and scientific ideals for which the Institute must ever stand, was apparent in the remarks made by each one of the guests in turn, and at the close Mr. Dunn, in well-chosen words again expressed his appreciation of the assistance and the cordial good will he had received from all during his period of administration.

Thus closed a most charming and delightful banquet, but perhaps the words of Past-President Scott might more fittingly describe it. He spoke of its future effects and called it a "Construction Institute Banquet."

Associates Transferred on May 21, 1912

The following Associates were transferred to the grade of Member in the Institute at the meeting of the Board of Directors held on May 21, 1912.

Herbert R. Harper, City Electrical Engineer, Municipality of Melbourne, Australia.

Frank F. Fowle, Consulting Electrical Engineer, Chicago, Ill.

Julien E. Dalemont, Consulting Electrical Engineer, Hamilton, Ont.

John B. Klumpp, Inspecting Engineer, Philadelphia, Pa.

Samuel H. Rippey, Consulting Engineer. Philadelphia, Pa.

L. T. Robinson, General Electric Company, Schenectady, N. Y.

Recommended for Transfer May 14, 1912

The following Associates,were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on May 14, 1912. Any objection to the the transfer of any of these Associates should be filed at once with the Secretary.

Clifton W. Wilder, Electrical Engineer, Public Service Commission, New York.

Arthur C. Pratt, Electrical Engineer, United Missouri River Power Company, Helena, Montana.

M. O. Troy, Manager of Sales, General Electric Company, Schenectady, N.Y.

William J. Crumpton, Manager of Chicago Office, D. C. and W. B. Jackson, Chicago.

Frederic A. DeLay, Professor of Electrical Engineering, Colorado State Agricultural College, Fort Collins, Colo.

O. S. More, Chief Electrical Engineer, Fairbanks Morse Electrical Mfg. Co., Indianapolis, Ind.

Associates Elected May 21, 1912

Ahlborn, George Henry, Assistant Physicist, Bureau of Standards, Washington, D. C.

Alexander, George Henry Lee, Manager, Public Service Operating Co., Belvidere, Ill.

Alexander, Hugh Gordon, Chief Operator, Winnipeg Electric Railway; res., 524 Spence St., Winnipeg, Man.

Alexandre, William, 220 Wadsworth Ave., New York, N. Y.

Ashmead, Edward Walsmley, Secretary to Vice-President J. G. White & Co., 43 Exchange Place, New York, N. Y.

Barnes, Charles Ballon, Works Engineer, Western Electric Co., Hawthorne; res., 229 Wisconsin Ave. Oak Park, Ill.

Bear, Charles Shelby, Chief Electrician, Copper Queen Consolidated Mining Co., Bisbee, Ariz.

Beebee, Ralph Agustus, Construction Engineer, Federal Telegraph Co., San Francisco; res., 551 University Ave., Palo Alto, Cal

Benjamin, Harold A., with B. J. Arnold, 521 San Fernando Bldg.; res., 1036 Lake St., Los Angeles, Cal.

Bennett, Robert Manning, Dynamo Tender, N. Y. C. & H. R. R., 142nd St. & East River; res., 250 West 43rd St., New York, N. Y.

Besley, Stephen Henry, Student, University of Utah; res., 618 2nd East St., Salt Lake City, Utah.

Betts, Hyla, Electrical Engineer, Rio de Janeiro Tram. Lt. & Pr. Co., 76 Avenida Central, Rio de Janeiro, Brazil, S. A.

Bird, Fred Berger, Meter-Man, Light and Power Commission; res., 907 N. 4th St., Marquette, Mich.

Boatright, Harvey E., Electrical Superintendent, Central Mexico Light & Power Co., San Luis Potosi, Mex.

Boyce, Frank George, Erecting Engineer, Allis-Chalmers Co., Milwaukee, Wis.

Boyer, Lee, Superintendent of Hydroelectric Properties, Consolidated Power & Light Co., Deadwood; res., Spearfish, S. D.

Braeder, Frederick A., Inspector, Western Electric Co., New York, N. Y.; res., 55 Columbia Ave., Newark, N. J.

Brown, Roscoe Dudley, Salesman, Electric Service Supplies Co.; res., 341 6th Ave., Pittsburgh, Pa.

Brundige, Daniel Lee, Station Superintendent, Telluride Power Co., Provo, Utah.

Buchanan, Elmer Clarence, Telephone Engineer, Pacific Tel. & Tel. Co., 519 Columbia Bldg., Spokane, Wash.

Buel, F. Leandro, Engineer in charge, Empresa Hidro-Electrica, Tepic, Mex.

Bull, Anders H., Electrical Engineer, Public Service Commission, 154 Nassau St., New York; res., 519 Eighth St., Brooklyn, N. Y.

Burchard, Anson Wood, General Electric Co., 30 Church St.; res., 21 Front St., Schenectady, N. Y.

Butler, Earnest Lorn, Superintendent Light & Power Department, 306 N. Pine St., Ellensburg, Wash.

Carolin, Norbert, Electrical Inspector, Western Electric Co., 463 West St.; res., 555 West 156th St., New N. Y.

Carpenter, Charles F., Test Man, General Electric Co.; res., 53 Thompson St., Schenectady, N. Y.

Cary, Miles, Electrical Engineer, Crystal Coal & Coke Co., Crystal, W. Va.

Chapman, Alexander Kesterson, Record Clerk, Plant Engg. Dept., Pacific Tel. & Tel. Co., 724 Fidelity Bldg., Tacoma, Wash.

Chase, Samuel Adams, Special Representative, Westinghouse Electric & Mfg. Co.; res., 7143 Meade St., Pittsburgh, E. E., Pa.

Coleman, Lindley Gilman, Secretary and Treasurer, Meridian Light & Ry. Co.; res., 2600 8th St., Meridian, Miss.

Collamore, Ralph, Consulting Engineer, 710 Washington Arcade Bldg., Detroit, Mich.

Collar, Elmer H., General Foreman, Missoula Light & Water Co.; res., 301 S. Second St., Missoula, Mont.

Converse, Maurice, Engineer, Standard Welding Co.; res., 2096 East 40th St., Cleveland, Ohio.

Cooper, Sidney Bruce, Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh; res., 463 Biddle Ave., Wilkinsburg, Pa.

Cottman, Lewis Warrington, Superintendent & Chief Engineer, Palmetto Phosphate Co., 812 Keyser Bldg., Baltimore, Md.

Cross, Frank Leonard, General Manager, Madison Gas & Electric Co.; res., 1233 Sherman Ave., Madison, Wis.

Crowder, Alexander Norman, Draughtsman, N. Y., N. H. & H. R. R., Room 308 Railroad Bldg., New Haven, Conn.

Cullen, William Kenneth, Superintendent of Electric Distribution, United Light & Power Co., 57 Post St., San Francisco, Cal.

Daniel, Roderick Llewellyn, Electrical Inspector, General Inspection Co., 1236 Plymouth Bldg., Minneapolis, Minn.

Darling, Arthur Roden, Vice-President and Electrical Superintendent, Edwards Instrument Co., 850 Massachusetts Ave., Indianapolis, Ind.

Davis, Basil Duke, Chief Engineer and Superintendent of Construction, New York and Honduras-Rosario Mng. Co., Honduras, C. A.

Davison, Robert Thomas, Chief Electrician, Veracruz Terminal Co., Veracruz, Mex.

Dodge, Charles Rea Agnew, Electrical Superintendent, Canadian Copper Co., Copper Cliff, Ont.

Donovan, Homer A., Switchboard Operator, Winnipeg Electric Railway Co., Terminal Sta.; res., 288 Simcoe St., Winnipeg, Man.

Doty, Albert J., Electrical Engineer, Lansden Co., Newark, N. J.; res., Mt. Vernon, N. Y.

Duffy, Ralph E., Superintendent, Greenfield Electric Light & Power Co., Greenfield, Mo.

Eaton, George Myron, Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh; res., 726 East End Ave., Wilkinsburg, Pa.

Edgar, Leavitt, L., Edison Electric Ill. Co. of Boston, 39 Boylston St., Boston, Mass.

Ellis, Albert Llewellyn, Switchboard Operator, Helena Light & Railway Company Substation, Helena, Mont.

Faber, Joseph Frederick, Assistant Master Mechanic, United Engineering & Contracting Co., Lockport, N.Y.

Fletcher, John W., Electrical Inspector, Public Service Co. of Northern Illinois; res., 320 Lake St., Oak Park, Ill.

Folger, Roy Cooke, Benson Mines Co., Benson Mines, N. Y.

Froelich, John Magee, Field Engineer, Arc. Lamp Dept., Allegheny County Light Co., 435 Sixth Ave.; res., 5825 Rippey St., Pittsburgh, Pa.

Gardiner, Harry Myron, Engineer, Northway Motor & Mfg. Co.; res., 1442 24th St., Detroit, Mich.

Gerstle, Ralph J. F., Assistant Engineer, New York, New Haven & Hartford Railroad; res., 254 W. 139th St., New York, N. Y.

Gibbs, Louis D., Superintendent of Advertising, Edison Electric Illuminating Co., 39 Boylston St., Boston, Mass.

Gill, Joseph Henry, Switchboard Inspector, General Electric Co.; res., 3 Jackson Place, Schenectady, N. Y.

Gilmore, Harry Bassett, Manager, Western Electric Co., 115 Purchase St., Boston, Mass.

Gove, Henry Shimer, Engineer in charge hydrographic work, Tallahatchie Drainage Commission, Tunica, Miss.

Green, Harold Vincent, Acting Assistant Sales Agent, Power & Mining Dept., General Electric Co., Schenectady, N. Y.

Greenawalt, Albert Earl, Chief Electrician, Chicago, Indiana & Southern Railroad, Gibson, Ind.

Grinsted, William Herbert, Telephone Engineer, Siemens Brothers & Co., Ltd., Woolwich, Kent, Eng.

Harris, Carl Everett, Assistant Shop Engineer, Illinois Central Railroad, Central Station; res., 740 Oakwood Blvd., Chicago, Ill.

Harris, Lester Joslyn, Instructor, David Ranken Jr. School of Mechanical Trades; res., 4664 Evans Ave., St. Louis, Mo.

Hatch, Edwin Glentworth, Manager, Clark Electric & Mfg. Co., 149 Broadway, New York; res., 559 27th St., Brooklyn, N. Y.

Haydon, Gerald Summersell, Electrical Superintendent, Nova Scotia Steel & Coal Co., Ltd., Wabana, Newfoundland.

Hijar y Haro, Jose, Rolling Stock Inspector, National Railways of Mexico, Aguascalientes, Mex.

Holloway, Asher Earl, Manager, New Business Dept., San Diego Consolidated Gas & Electric Co.; res., 9th and A Ave., Coronado, Cal.

Holtzapple, Leonard Harold, Chief Electrician, Winona Copper Co., Winona, Mich.

Holman, Arthur John, Electrical Engineer, Crocker-Wheeler Co., 118 North 16th St., East Orange, N. J.

Hopkins, Basil Brooke, Campania Real del Monte y Pachuca, Pachuca, Hgo., Mex.

Hopwood, J. M., Mechanical and Electrical Engineer, Merchants Coal Co., Boswell; res., Jerome, Pa.

Hoyt, Henry Campbell, Commercial Engineer, Power & Mining Dept., General Electric Co., Schenectady, N. Y.

Irwin, Theodore Ernest, Wire Chief, Southwestern Home Telephone Co., res., 326 W. State St., Redlands, Cal.

JAY, WILLIAM CHARLES, Electrical Foreman, Isthmian Canal Commission, Gatun, C. Z.

JOHNSON, EWART FRANK, Superintendent, Battle Creek Sta., Telluride Power Co., Pleasant Grove, Utah.

JONES, BARRY HAYES, Engineering Dept., American Tel. & Tel. Co., 15 Dey St., New York, N. Y.

JONES, RAY EVERETT, Chief Electrician, Inland Portland Cement Co., Metaline Falls, Wash.

JULIAN, OLIVER GERALD, Inspector, Electrical Dept., N.Y.N.H.& H. R.R., 254 Hugenot St., New Rochelle, N.Y.

KAELIN, FREDERICK THOMAS, Assistant Chief Engineer, Shawinigan Water & Power Co., Room 611, Power Bldg., Montreal, Can.

KALB, WARREN C., Assistant Foreman, National Carbon Co.; res., 1286 Beach Ave., Lakewood, Ohio.

KEARNEY, GRAHAM, District Agent, Canadian General Electric Co., Prince Rupert, B. C.

KEITH, ALEXANDER E., Chief Engineer, Automatic Electric Co., Chicago; res., Park Ave. & 3rd St., Hinsdale, Ill.

KELSO, LESLIE ERSKINE ALLAN, Instructor in Mathematics and Physics, Telluride Power Co., Provo, Utah.

KENNEDY, FREEMAN WINNER, Electrical Engineer, General Motors Co., Detroit, Mich.

KENNEDY, GEORGE MAISCH, Electrical Engineer, Lehigh Coal & Navigation Co., Lansford, Pa.

KILBURN, EDWARD DOUGLAS, Local Manager, Westinghouse Electric & Mfg. Co., 617 Chamber of Commerce Bldg., Rochester, N. Y.

KINNEY, RALPH M., Electrical Engineer, Burgess Sulphite Fibre Co., Berlin, N. H.

KIRK, WALTER LEWIS, Foreman, United Missouri River Power Co., Canyon Ferry, Mont.

KNEISEL, ARTHUR, Assistant Engineer, North Electric Co.; res., 2132 West 100th St., Cleveland, Ohio.

KNIGHT, ARTHUR FRANKLIN, Designing Electrical Engineer, General Electric Co., Schenectady, N. Y.

KOTTENBACH, ERNEST EDWARD, Electrical Engineer, New York Edison Co., 55 Duane St., New York, N. Y.

KRUGER, JOHN L., Electrical Contractor 137 Grand Ave., Brooklyn, N. Y.

LAURENCOT, HENRY J., Inspector of Electrical Construction, Edison Electric Ill. Co., 360 Pearl St.; res., 2312 85th St., Brooklyn, N. Y.

LEE, LOUIS ROBERT, Chief Engineer, E. W. Clark and Co., 909 Wyandotte Bldg., Columbus, Ohio.

LIMON, GREGORIO, Electrical Contractor, National Carbridge Factory, Orizaba, Mexico.

LUSBY, FRANK JEROME, Traffic Dept., Southern Bell Tel. & Tel. Co., 344 D. Street, N. W., Washington, D. C.

MANNING, JOHN J. L., Electrical Engineering Dept., Boston Elevated Railway, 552 Harrison Ave., Boston; res., 47 Monument Ave., Charlestown, Mass.

MARTIN, JAMES RENWICK McINTOSH, Correspondent in Sales Dept., Westinghouse Electric & Mfg. Co.; res., 401 N. Highland Ave., Pittsburgh, Pa.

MASON, ROY, Advertising Bureau, Crocker-Wheeler Co., Ampere, N. J.; res., 53 Washington Square, South, New York, N. Y.

MAWHINNEY, HARRY CLIFTON, Electrician, Pennsylvania Railroad Co., 314 Babcock St.; res., 694 East Eagle St., Buffalo, N. Y.

McBERTY, FRED POW, Electrical and Mechanical Engineer, National Electric Welder Co., Warren, Ohio.

McCARTHY, ELMER TAYLOR, Instructor Drawing Dept., Georgia School of Technology, Atlanta, Ga.

McGOVERN, WILLIAM ROBBINS, Engineer of Inventory and Appraisals, Central Group, Bell Telephone Companies; res., 4731 Dover St., Chicago, Ill.

McMILLAN, JAMES PALMER, Salesman, Westinghouse Electric & Mfg. Co., American Bldg.; res., 423 Elizabeth Ave., Charlotte, N. C.

Meade, John Theodore, Chief Electrician, Russell, Burdsall & Ward Bolt & Nut Co.; res., 55 Pomingo St., Port Chester, N. Y.

Miller, Otto Charles, Foreman Undergound Dept., Los Angeles Gas & Electric Corp'n.; res., 220 South Ave., 18 Los Angeles, Cal.

Moore, Fay, Power House Foreman, Arkansas Valley Railway Light & Power Co., Victor, Colo.

Morehead, William Clyde, Secretary and Treasurer, National Light & Power Co., Pierce Bldg., St. Louis, Mo.

Morphet, Frank Howard Kester, Construction Foreman, General Electric Co., 11th Floor Witherspoon Bldg., Philadelphia, Pa.

Morse, Victor Edward, Power House Electrician, Sierra & San Francisco Power Co., Stanislaus, Cal.

Moses, Alonzo Lemuel, Electrical Engineer, W. P. Crockett Co, 502 S. Canal St.; res., 3821 Lake Ave., Chicago, Ill.

Mulrony, Marion Alvin, Chief Engineer, Maritime Wireless Telegraph Co., Ltd., Randwick, Sydney, Australia.

Murray, Frank E., Secretary-Treasurer and General Manager, Louisiana Light Power & Traction Co., Louisiana, Mo.

Murray, Joseph Norris, Engineering Dept., Crocker-Wheeler Co., 3920 Broadway, New York, N. Y.

Neely, Charles, Superintendent, Arkansas Valley Railway Light & Power Co., Cripple Creek, Colo.

Newman, Max Gibson, Laboratory Assistant, General Electric Co.; res., 25 Abbott St., Pittsfield, Mass.

Nichols, Horace E., Electrical Engineer, General Electric Co.; res., 11½ North College St., Schenectady, N.Y.

Oehlman, Cyrus F., Heating Dept., Denver Gas & Electric Light Co., 900 15th St., Denver, Colo.

Oliver, Clifford Rylander, Assistant Electrical Engineer, Power Construction Co., Shelburne Falls, Mass.

Olsen, Valdemar, Meter Tester, Electricity Dept., Shanghai Municipal Council; res., 29 Ward Road, Shanghai, China.

O'Reilly, Richard Hamilton, Student, Manitoba University, Winnipeg, Man.

Owens, Michael Francis, Secretary, Automatic Refrigerating Co., 630 Capitol Ave.; res., 143 Park St, Hartford, Conn.

Packard, Spicer Dwight, Student Engineer, General Electric Co.; res., 53 Thompson St., Schenectady, N.Y.

Padfield, Stewart Elliot, Operator, Helena Light & Railway Co., Helena, Mont.

Palmer, Charles Edward, Chief, Long Distance Observ. Dept., Canadian Bell Telephone Co., Toronto, Ont.

Payne, Frank Tisdale, Superintendent Truckee River General Electric Co.; res., 242 West Liberty St., Reno, Nev.

Payne, Lucius Fawkes, Manager, Peoples Water & Light Co., Harrisburg, Ill.

Peebles, Leighton H., Asst. Construction Superintendent, J. G. White & Co., Columbia, S. C.

Pettebone, Lauren A., Chief Clerk, United States Light & Heating Co.; res., 307 Buffalo Ave., Niagara Falls, N. Y.

Pierce, Thomas Stebbins, Wire Chief, Iowa Telephone Co.; res., 1802 High St., Des Moines, Ia.

Pollard, L. E., Sales Engineer, Dwyer-Field Co., 681 Endicott St., St. Paul, Minn.

Pope, Clarence James, Apprentice, Crocker-Wheeler Co., Ampere; res., 73 Prospect St., East Orange, N. J.

Pratt, Chester Caine, District Plant Superintendent, Mountain States Tel. & Tel. Co.; res., 933 Lincoln St., Salt Lake City, Utah.

Quinn, Walter Joseph, Assistant to Chief Engineer, Third Avenue Railroad Co., 2400 Third Ave.; res., 593 Beach Terrace, New York, N. Y.

Rhett, Albert Haskell, Structural Engineer, New York, Westchester & Boston Ry. Co., Room 3144, Grand Central Terminal, New York, N. Y.

Rich, Milton, Asst. Chief Draughtsman, Distribution Div., Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.

Richardson, Rodney Guy, Wire Chief, Helena Automatic Telephone Co., Helena, Mont.

Ridgway, Percy Harry, Consulting Engineer, 709 Central Bldg., Seattle, Wash.

Riley, Maynard Hugh, Facilities Engineer, Central Union Telephone Co., Springfield, Ill.

Roberts, David Huyler, Vice-President and Treasurer, James H. Roberts Elevator Co., 430 W. Broadway, New York, N. Y.

Rohde William Charles Frederick, Student Engineer, General Electric Co., Pittsfield, Mass.

Schindler, Charles, Power House Operator, Northern California Power Co., 350 Post St., San Francisco, Cal.

Shields, Harvey Henry, General Flume Foreman, Sierra & San Francisco Power Co., Stanislaus, Cal.

Siebert, William Arthur, Electrician, Great Falls Power Co., Rainbow Falls, Mont.

Soule, Gardner F., Electrical Inspector, Connecticut Co., Room 308 Railroad Bldg., New Haven, Conn.

Stephany, Quirin, Superintendent, Light & Water Dept., Crystal Falls, Mich.

Stewart, Samuel Barrett, Jr., Designing Electrical Engineer, General Electric Co.; res., 7 Stratford Rd., Schenectady, N. Y.

Stockwell, Frank Clifford, Instructor in Electrical Engineering, Stevens Institute of Technology, Hoboken, N. J.

Sylvester, Wilbur Vincent, Overhead Line Inspector, Lighting Department, City of Seattle; res., 4831 Spencer St., Seattle, Wash.

Szilas, Oskar, Electrical Engineer, Ganz Electric Co., Budapest, Hungary.

Tabossi, Hector, 12½ St. James Ave., Boston, Mass.

Tear, Herbert Lloyd, Draftsman, Woods Motor Vehicle Co., 2500 Cottage Grove Ave.; res., 3230 Walnut St., Chicago, Ill.

Thomas, Charles Graham Mease, Vice-President and General Manager, New York & Queens Elec. Lt. & Pr. Co., 244 Jackson Ave., Long Island City, N. Y.

Thompson, Ross Emile, Electrician, Muskogee Gas & Electric Co.; res., 120 South D St., Muskogee, Okla.

Thomson, Richard G., Chief Electrician, Edmonton Power House; res., 642 4th St., Edmonton, Can.

Throop, George Huntington, Assistant Electrical Engineer, J. G. White & Co., Inc., Alaska Commercial Bldg., San Francisco, Cal.

Thurston, Ernest Bert, Designing Engineer, General Electric Co.; res., 120 Lyman St., Pittsfield, Mass.

Townsend, John Robert, Manager, J. C. Farrar & Co., 1008 Yeon Bldg., Portland, Ore.

Turnbull, Thomas Leroy, Electrical Engineer, P. D. McLaren Ltd., Calgary, Alberta, Canada.

Varney, Gordon Edward, President, Varney Electric Supply Co., 235 South Meridian St., Indianapolis, Ind.

Volkmann, William, Jr., Assistant to Superintendent Power Plant, Westinghouse Electric & Mfg. Co., Pittsburgh; res., 515 Kelly St., Wilkinsburg, Pa.

Wade, Raymond Selden, 95 West Genessee St., Buffalo, N. Y.

Wakefield, Walter Harold, Patent Solicitor, Fetherstonhaugh & Son, 313 McGill Bldg., Washington; res., 129 Maple Ave., Takoma Park, D.C.

Ward, Harry Irvin, Superintendent Electrical Dept., Muskogee Gas & Electric Co., 27 W. Okmulgee Ave., Muskogee, Okla.

Ward, Percy Walton, Engineer, Testing Laboratory, General Electric Co., Schenectady, N. Y.

White, William Penn, Railway and Trac. Engg. Dept., General Electric Co.; res., 14 Parkwood Blvd., Schenectady, N. Y.

Whyte, Herbert Barclay, Assistant Supply Engineer, Canadian General Electric Co., King St., Toronto, Ont.

Wilder, Bertram DeWitt, Facilities Engineer, Indiana Div'n., Central Union Telephone Co., Indianapolis, Ind.

Wilbur, Ray Seth, Engineer, Western Electric Co., 463 West St., New York, N.Y.; res., 261 New York Ave., Jersey City, N.J.

Williams, Edmund Farrington, Electrical Engineer, Westinghouse Electric & Mfg. Co., 165 Broadway; res., 620 West 122nd St., New York, N. Y.

Winter, William Henry, General Plant Superintendent, Bell Telephone Co. of Canada; res., 113 Hutchison St., Montreal, Can.

Winton, Robert Prince, Draughtsman, Elec. Engg. Dept., N. Y. N. H. & H. R. R.; res., 136 Canner St., New Haven, Conn.

Wolf, Robert Farber, Traffic Engg. Dept., Bell Telephone Co.; res., 210 Pine St., Harrisburg, Pa.

Zimmer, Albert Russell, Demonstrator in Electrical Engineering, University of Toronto; res., 32 Delaware Ave., Toronto, Ont.

Total 175.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any member or Associate objecting to the election of any of these candidates should so inform the Secretary before June 25, 1912.

11483 Eaves, A. J., New York, N. Y.
11484 Heitner, W. O., Chicago, Ill.
11485 Stone, F. L., Schenectady, N. Y.
11486 Kilborn, H., New York, N. Y.
11487 Rees, M. G. Portland, Ore.
11488 Trask, W. H. Jr., Boise, Idaho.
11489 Tait,W.M.,Glenwood Spgs,Colo.
11490 Bennett, H.G.R.,Youngstown,O.
11491 Eden, T. S., Schenectady, N. Y.
11492 Henderson, S.L.,Cleveland,Ohio.
11493 McColl,A.E., Glasgow, Scotland.
11494 Tennis, M. F., Pittsburgh, Pa.
11495 Jones, E., Winnipeg, Man.
11496 Montgomery,M.,Winnipeg,Man.
11497 Cornelius, A., Brooklyn, N. Y.
11498 Badgley,A.D.,Schenectady,N.Y.
11499 Cohen, N.D.W., Jobabo, Cuba.
11500 Mel, W. B., San Francisco, Cal.
11501 Carson, J., Mexico, D. F.
11502 Rowlands, R. D., Chicago, Ill.
11503 Eaton, B. L., Guayamo, P. R.
11504 Ishikawa, Y., Kyoto, Japan.
11505 Mikkelsen, A. H., Newark, N. J.
11506 Winetraub, A. I. M., New York, N. Y.
11507 Wreaks, W. B., Detroit, Mich.
11508 Hunt, P. B., West Allis, Wis.
11509 Kellogg, R. G.; Milwaukee, Wis.
11510 Aikman, A. N., Johannesburg, Transvaal.
11511 Wells, M. H., Schenectady, N. Y.
11512 Fraser,W.H.R.,Vancouver,B. C.
11513 Putnam, E. F., Wellesley Farms, Mass.
11514 Slaney, H. A., Chicago, Ill.
11515 Krum, H. L., Chicago, Ill.
11516 Eshleman, S. K., Jr., New York, N. Y.
11517 Norton, H. H., Detroit, Mich.
11518 Reynolds, A. S., Jr., New York, N. Y.
11519 Cecil, B. R., Jackson, Mich.
11520 Moss, S. A., Lynn, Mass.
11521 Millham, L. F., Scotia, N. Y.
11522 Durand, W. F., Stanford University, Cal.
11523 de Weerth, W., Milwaukee, Wis.
11524 Delaney,W.J., Schenectady,N.Y.
11525 Chapin, N. J., Denver, Colo.
11526 Schwedes, W. F., Duluth, Minn.
11527 Hallenbeck,M. H.,Dallas, Texas,
11528 Walters, R. H., Salt Lake City, Utah.
11529 Hamilton, P. D. G., Needham, Mass.

11530 Schermerhorn, J. L., Pittsfield, Mass.
11531 Archibald, E. B., Montreal, Que.
11532 Hojel, A. C. Mexico, D. F.
11533 Lowenberg, M. J., Albany N. Y.
11534 Miller, P.C., Superior, Wis.
11535 Minott,A.W.Jr.,Cedar Rapids,Ia.
11536 Donle, H. P., Providence, R. I.
11537 Kentish-Rankin,I.L., PointGrey, B. C.
11538 Czeija, K. E., Brooklyn, N.Y.
11539 Little, J. J. New York, N. Y.
11540 Elmore, O., Bellingham, Wash.
11541 Lanyon, H.R., Bilston, England.
11542 Littig, A. L., Vancouver, B.C.
11543 Hansen, H.J., Erie, Pa.
11544 Jones, C. F., Bucyrus, Ohio.
11545 Reese, H., Wilkes-Barre, Pa.
11546 Webber, F.M., Ft.Wayne, Ind.
11547 Davis, C. H., Pittsburgh, Pa.
11548 Shimizu, G., Kyoto, Japan.
11549 Moore, J. E., New York, N. Y.
11550 Fox, G., Ft. Wayne, Ind.
11551 Lindstrom,J.D., EllwoodCity,Pa.
11552 Deving, M.A., Washington,D.C.
11553 Simpson, S., Bradford, Eng.
11554 C. leMaistre, London, Eng.
Total 72.

Students Enrolled May 21, 1912

5139 Hafer, G.M., Ohio Northern Univ.
5140 Lill, A. C., Armour Inst. Tech.
5141 Parkinson,R.W.,ThroopPoly.Inst.
5142 Perry,E. R., Univ. of Washington.
5143 Haller, L. W., Oregon Agri. Coll.
5144 Ferguson, B., Throop Poly.Inst.
5145 Cruthers, W. M., Univ. of Toronto
5146 Beach, R., New Hampshire Coll.
5147 Quest, J. F., Purdue University.
5148 Stansel, W. G., Armour Inst.Tech.
5149 Dutt, M. L., Univ. of Illinois.
5150 Nourse, F. M., Univ. of Illinois.
5151 Hunter, W., Mass. Inst. Tech.
5152 Coup, F. T., Univ. of Wisconsin.
5153 Fisher, O. W., Jr., Montana A. & M. College.
5154 Dodd, R. L., Univ. of Wisconsin.
5155 Belknap, J. H., Oregon Agri.Coll.
5156 Smith, G. M., Penna. State Coll.
5157 Gulley, L. R., Univ. of Illinois.
5158 Bruback, T. M., Cornell Univ.
5159 Soake, L. C., Purdue University.
5160 Cohen, L. W., Cooper Union.
5161 Spears,J.W.,Georgia School Tech.
5162 Ariston, A. J., Carnegie Tech. Sch.
5163 Forsyth, P., Penn. State College.
5164 Willson, W. G., Montana A. & M. Coll.
5165 Findley, P. B., Princeton Univ.
5166 MacNabb,A.W.,StevensInst.Tech
5167 McGhie, W. G., Univ. of Toronto.
5168 Howard-Soler, A.,Yale University.
5169 Mathewson, G. T., Jr., Yale Univ.
5170 Sawford, J. H., Yale University.
5171 Wright, L. E., Wash. State Coll.
5172 Ramsay, J. A., Wash. State Coll.
5173 Kochhar, B. D., Wash. State Coll.
5174 Lake,N.L.,Washington State Coll.
5175 Winne, L. A., Univ. of Penn.
5176 Sullivan, C. M., Univ. of Illinois.
5177 Chavous. A. M., Univ. of Illinois.
5178 Merris, C. E., Univ. of Illinois.
5179 Derry, H. G., Univ. of Illinois.
5180 Keiler, F. S., Univ. of Illinois.
5181 Gordon, W. G., Univ. of Illinois.
5182 Fedde, H., University of Illinois.
5183 Narkinsky, C. S., Univ. of Illinois
5184 Smith, C. D., Worcester Poly.Inst.
5185 Staveley, E. B., Penna. State Coll.
5186 Prior, A. A., Harvard College.
5187 Ingalls, R. D., Univ. of Illinois.
5188 Doane, H. A. Univ. of Illinois.
5189 Saunders, H. O., Univ. of Illinois.
5190 Schenck, C., Univ. of Illinois.
5191 Habryl, V. B., Univ. of Illinois.
5193 Edwards,A.H.,Colorado Agri.Coll.
5194 Loebenstein, J., Columbia Univ.
5195 Nafziger, H. T., Univ. of Illinois.
5196 Vandeveer, H. E., Univ.of Illinois.
5197 Bainbridge, W., Univ. of Penn.
5198 Davis, R. N., Univ. of Penn.
5199 Miller, E. F., Univ. of Penn.
5200 Seltzer, L. W., Univ. of Penn.
5201 Stortz, J., Univ. of Penn.
5202 Weiss, B. M., Univ. of Penn.
5203 Williams, V. C., Jr.,Univ. of Penn.
5204 Beal, R. R., Stanford University.
5205 Field, A. J., Stanford University.
Total, 66

OFFICERS AND BOARD OF DIRECTORS, 1911-1912.

PRESIDENT.

(Term expires July 31, 1912.)

GANO DUNN.

JUNIOR PAST-PRESIDENTS.

LEWIS BUCKLEY STILLWELL.

DUGALD C. JACKSON

VICE-PRESIDENTS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
MORGAN BROOKS.	DAVID B. RUSHMORE.
HAROLD W. BUCK.	WILLARD GILBERT CARLTON.
PERCY HOLBROOK THOMAS.	CHARLES WATERMAN STONE.

MANAGERS.

(Term expires July 31, 1912.)	(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
ARTHUR W. BERRESFORD.	HOWEL H. BARNES, JR.	FRED S. HUNTING.
WILLIAM S. MURRAY.	ROBERT GIVEN BLACK.	NORMAN W. STORER.
HENRY H. NORRIS.	WALTER S. RUGG.	WILLIAM S. LEE.
SEVERN D. SPRONG.	CHARLES E. SCRIBNER.	FARLEY OSGOOD.

TREASURER.	(Term expires July 31, 1912.)	SECRETARY.
GEORGE A. HAMILTON.		F. L. HUTCHINSON.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
ARTHUR E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN WILLIAM LIEB, Jr., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09
LEWIS BUCKLEY STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.

*Deceased.

HONORARY SECRETARY.

RALPH W. POPE,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York

STANDING COMMITTEES.

Revised to June 1, 1912.

EXECUTIVE COMMITTEE.

GANO DUNN, Chairman,
117 West 58th St., New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
F. L. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
CHARLES E. SCRIBNER, New York.
CHARLES W. STONE, Schenectady, N. Y.
WALTER S. RUGG, New York.

FINANCE COMMITTEE.

ARTHUR W. BERRESFORD, Chairman,
Cutler-Hammer Mfg. Co., Milwaukee, Wis.
HOWEL H. BARNES, JR., New York.
WALTER S. RUGG, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
FREDERICK BEDELL, Ithaca, N. Y.
MORGAN BROOKS, Urbana, Ill.
ALBERT F. GANZ, Hoboken, N. J.
OTIS ALLEN KENYON, New York.

MEETINGS AND PAPERS COMMITTEE.

HAROLD W. BUCK, Chairman,
49 Wall St., New York.
ALBERT F. GANZ, Hoboken, N. J.
BANCROFT GHERARDI, New York.
PETER JUNKERSFELD, Chicago, Ill.
JOHN PRICE JACKSON, State College, Pa.
WILLIAM HENRY POWELL, Milwaukee, Wis.
LEWIS T. ROBINSON, Schenectady, N. Y.
DAVID B. RUSHMORE, Schenectady, N. Y.
GEORGE FRANCIS SEVER, New York.
FRANK JULIAN SPRAGUE, New York.
SEVERN D. SPRONG, Brooklyn.
PERCY HOLBROOK THOMAS, New York.

EDITING COMMITTEE.

WALTER I. SLICHTER, Chairman,
Columbia University, New York
HORATIO A. FOSTER, Yonkers, N. Y.
ALBERT F. GANZ, Hoboken, N. J.
ADDAMS S. McALLISTER, New York.
HENRY H. NORRIS, Ithaca, N. Y.

BOARD OF EXAMINERS.

WILLARD GILBERT CARLTON, Chairman,
Grand Central Station, New York.
MAURICE COSTER, New York.
ALBERT F. GANZ, Hoboken, N. J.
WALTER I. SLICHTER, New York.
PERCY HOLBROOK THOMAS, New York.

SECTIONS COMMITTEE

PAUL M. LINCOLN, Chairman,
P. O. Box 911, Pittsburgh, Pa.
GEORGE FRANCIS SEVER, New York.
WALTER S. RUGG, New York.
GEORGE A. HOADLEY, Swarthmore, Pa.
SAMUEL G. McMEEN, Chicago, Ill.
and the chairmen of all the Sections.

STANDARDS COMMITTEE.

ARTHUR E. KENNELLY, Chairman,
Harvard University, Cambridge, Mass.
COMFORT A. ADAMS, Secretary,
Harvard University, Cambridge, Mass.
FREDERICK BEDELL, Ithaca, N. Y.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Perth Amboy, N. J.
BENJAMIN G. LAMME, Pittsburgh, Pa.
WILBUR L. MERRILL, Schenectady, N. Y.
HAROLD PENDER, Boston, Mass.
WILLIAM H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburgh, Pa.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
J. FRANKLIN STEVENS, Philadelphia, Pa.

CODE COMMITTEE.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York
FRANCIS ELLIOT CABOT, Boston, Mass.
JOSEPH C. FORSYTH, New York.
HARRY BARNES GEAR, Chicago, Ill.
FARLEY OSGOOD, Newark, N. J.
A. M. SCHOEN, Atlanta, Ga.
JOHN B. TAYLOR, Schenectady, N. Y.
HOWARD SAUNDERS WARREN, New York.
HUBERT S. WYNKOOP, New York.

LAW COMMITTEE.

CHARLES A. TERRY, Chairman,
165 Broadway, New York
CHARLES L. CLARKE, New York.
CLIFTON V. EDWARDS, New York.
FRED S. HUNTING, Fort Wayne, Ind.
ADDAMS S. McALLISTER, New York.

SPECIAL COMMITTEES.

Revised to June 1, 1912.

RAILWAY COMMITTEE.

FRANK JULIAN SPRAGUE, Chairman,
165 Broadway, New York
EDWIN BRITTON KATTE, Vice-Chairman,
New York.
FREDERICK DARLINGTON, Pittsburgh, Pa.
JESSE HOOD DAVIS, Baltimore, Md.
LOUIS CHARLTON FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
DUGALD C. JACKSON, Boston, Mass.
WILLIAM S. MURRAY, New Haven, Conn.
WILLIAM B. POTTER, Schenectady, N. Y.
LEWIS BUCKLEY STILLWELL, New York.
BENJAMIN FRANKLIN WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

JOHN PRICE JACKSON, Chairman,
State College, Pa.
WILLIAM L. ABBOTT, Chicago, Ill.
MORGAN BROOKS, Urbana, Ill.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE FRANCIS SEVER, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
WALTER I. SLICHTER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.

HIGH TENSION TRANSMISSION COMMITTEE.

DAVID B. RUSHMORE, Chairman,
General Electric Company, Schenectady, N.Y
FRANK GEORGE BAUM, San Francisco, Cal.
ARTHUR C. BUNKER, Montclair, N. J.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
WILLIAM S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
PETER WILLIAM SOTHMAN, Toronto, Ont.
SEVERN D. SPRONG, Brooklyn, N. Y.
PERCY HOLBROOK THOMAS, New York.

ELECTRIC LIGHTING COMMITTEE.

PETER JUNKERSFELD, Chairman,
120 W. Adams Street, Chicago, Ill
ROBERT GIVEN BLACK, Toronto, Ont.
WILLIAM C. L. EGLIN, Philadelphia, Pa.
HENRY W. FISHER, Pittsburgh, Pa.
WILLIAM S. HULSE, New York.
WILLIAM B. JACKSON, Chicago, Ill
CHARLES FREDERICK LACOMBE, N. Y.
D. McFARLAN MOORE, Newark, N. J.
HENRY F. SANVILLE, Philadelphia, Pa.
NICHOLAS STAHL, Pittsburgh, Pa.
ARTHUR H. TIMMERMAN, St. Louis, Mo.
PHILIP D. WAGONER, Long Island City, L. I.

INDUSTRIAL POWER COMMITTEE.

WILLIAM HENRY POWELL, Chairman,
Allis-Chalmers Co., Milwaukee, Wis.
COMFORT A. ADAMS, Cambridge, Mass.
MORTON ARENDT, New York.
THOMAS EDSON BARNUM, Milwaukee, Wis.
RUSSELL STIMSON FEICHT, Pittsburgh, Pa.
FERD GUY GASCHE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
CHARLES KETCHAM NICHOLS, New York
BARTON ROY SHOVER, Youngstown, Ohio.
ROBERT BELDEN TREAT, Ampere, N. J.
R TSCHENTSCHER, Chicago, Ill.
NORMAN T. WILCOX, Lowell, Mass.

TELEGRAPHY AND TELEPHONY COMMITTEE

BANCROFT GHERARDI, Chairman,
15 Dey Street, New York.
MORGAN BROOKS, Urbana, Ill.
WILSON LEE CAMPBELL, Chicago, Ill.
MINOR M. DAVIS, New York.
FRANK BALDWIN JEWETT, New York.
WILLIAM MAVER, Jr., New York.
SAMUEL G. McMEEN, Chicago, Ill.
J. L. McQUARRIE, New York.
FRANKLIN HOLMES REED, Chicago, Ill.
FREDERICK K. VREELAND, New York.
J. GLEN WRAY, Chicago, Ill.
GEORGE MARSHALL YORKE, New York

ELECTROCHEMICAL COMMITTEE.

ALBERT F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J
MORTON ARENDT, New York.
PHILIP PRICE BARTON, Niagara Falls, N. Y.
CHARLES AVERY DOREMUS, New York.
CARL HERING, Philadelphia, Pa.
JOHN HAROLD MORECROFT, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

SEVERN D. SPRONG, Chairman,
360 Pearl Street, Brooklyn, N. Y.
HOWEL H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
CLYDE D. GRAY, New York.
WILLIAM S. HULSE, New York.
HENRY A. LARDNER, San Francisco, Cal.
H. ST. CLAIR PUTNAM, New York.
GEORGE IRVING RHODES, New York.
NORMAN WILSON STORER, Pittsburgh, Pa

SPECIAL COMMITTEES.—Continued.

Revised to June 1, 1912.

PUBLIC POLICY COMMITTEE.

JOHN J. CARTY, Chairman,
15 Dey St., New York.
HAROLD W. BUCK, New York.
JOHN H. FINNEY, Washington, D. C.
PAUL N. NUNN, Provo, Utah.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.
JAMES GILBERT WHITE, New York.

ADDITIONAL GRADE OF MEMBERSHIP COMMITTEE.

PERCY HOLBROOK THOMAS, Chairman,
2 Rector Street, New York.
BANCROFT GHERARDI, New York.
PAUL M. LINCOLN, Pittsburgh, Pa.
ADDAMS S. McALLISTER, New York.
SAMUEL REBER, New York.
CHARLES W. STONE, Schenectady, N. Y.
CALVERT TOWNLEY, New York.

MEMBERSHIP COMMITTEE.

CHARLES E. SCRIBNER, Chairman,
463 West Street, New York.
S. B. CHARTERS, San Francisco, Cal.
HENRY FLOY, New York.
GEORGE W. LAMKE, St. Louis, Mo.
A. A. MILLER, Seattle, Wash.
N. J. NEALL, Boston, Mass.
K. C. RANDALL, Pittsburgh, Pa.
DAVID B. RUSHMORE, Schenectady, N. Y.
A. M. SCHOEN, Atlanta, Ga.
H. CLYDE SNOOK, Philadelphia, Pa.
H. B. STABLER, Baltimore, Md.
J. G. WRAY, Chicago, Ill.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANCIS BLOSSOM, Chairman,
52 William St., New York.
PUTNAM A. BATES, New York.
OLIVER S. LYFORD, JR., New York.
LEWIS BUCKLEY STILLWELL, New York.

CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT.

GEORGE FRANCIS SEVER, Chairman,
13 Park Row, New York.
HAROLD W. BUCK, New York.
SAMUEL REBER, New York.
CHARLES P. STEINMETZ, Schenectady, N.Y.
HENRY G. STOTT, New York.
SCHUYLER SKAATS WHEELER,
Ampere, N. J.

ELECTROPHYSICS COMMITTEE.

EDWARD B. ROSA, Chairman,
Bureau of Standards, Washington, D. C.
EDWARD P. HYDE, Cleveland, O.
MALCOLM MacLAREN, Princeton, N. J.
EDWARD L. NICHOLS, Ithaca, N. Y.
HAROLD PENDER, Boston, Mass.
MICHAEL I. PUPIN, New York.
HARRIS J. RYAN, Stanford University, Cal.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
JOHN B. WHITEHEAD, Baltimore, Md.
FRANK A. WOLFF, Washington, D. C.

HISTORICAL MUSEUM COMMITTEE.

T. COMMERFORD MARTIN, Chairman,
29 West 39th St., New York
JOHN J. CARTY, New York.
CHARLES L. CLARKE, New York.
LOUIS A. FERGUSON, Chicago, Ill.
E. WILBUR RICE, JR., Schenectady, N. Y.
FRANK JULIAN SPRAGUE, New York.
CHARLES A. TERRY, New York.

INDEXING TRANSACTIONS COMMITTEE.

GEORGE IRVING RHODES, Chairman,
600 West 59th Street, New York.
MORTON GITHENS LLOYD, Chicago, Ill.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

C. O. MAILLOUX, President,
90 West St., New York
ARTHUR E. KENNELLY, Secretary,
Harvard University, Cambridge, Mass
COMFORT A. ADAMS, Cambridge, Mass.
LOUIS BELL, Boston, Mass.
JOHN J. CARTY, New York.
GANO DUNN (ex-officio), New York.
CARL HERING, Philadelphia, Pa.
JOHN W. HOWELL, Newark, N. J.
JOHN W. LIEB, Jr., New York.
RALPH D. MERSHON, New York.
EDWARD B. ROSA, Washington, D. C.
CHARLES F. SCOTT, New Haven, Conn.
CLAYTON H. SHARP, New York.
SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES P. STEINMETZ, Schenectady, N.Y.
SAMUEL W. STRATTON, Washington, D. C.

EDISON MEDAL COMMITTEE.

Appointed by the President.

Term expires July 31, 1916.

FRANK JULIAN SPRAGUE, New York.
SCHUYLER SKAATS WHEELER, Ampere, N. J.
W. D. WEAVER, New York.

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass
JOHN WILLIAM LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP PRICE BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
JAMES GILBERT WHITE, New York.

Term expires July 31, 1913.

COMFORT A. ADAMS, Cambridge, Mass.
CUMMINGS C. CHESNEY, Pittsfield, Mass.
CHARLES EDWARD LUCKE, Secretary, N.Y.

Term expires July 31, 1912.

WILLIAM S. BARSTOW, New York.
CHARLES A. TERRY, New York.

Elected by the Board of Directors from its own membership.

Term expires July 31, 1913.

LEWIS BUCKLEY STILLWELL, New York.
HOWEL H. BARNES, JR., New York.
SEVERN D. SPRONG, Brooklyn, N. Y.

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburgh, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY HOLBROOK THOMAS, New York.

Ex-officio Members.

Term expires July 31, 1912.

GANO DUNN, President, New York.
F. L. HUTCHINSON, Secretary.
GEORGE A. HAMILTON, Treasurer.

INSTITUTE REPRESENTATIVES.

Revised to June 1, 1912.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

LOUIS A. FERGUSON, Chicago, Ill.
LEWIS BUCKLEY STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.
GANO DUNN, New York.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

WALTER S. RUGG, New York.
HOWEL H BARNES Jr., New York.
GANO DUNN, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

CHARLES F. SCOTT, New Haven, Conn.
SAMUEL SHELDON, Brooklyn, N. Y.

ON RESUSCITATION COMMISSION.

ARTHUR E. KENNELLY, Cambridge, Mass.
ELIHU THOMSON, Swampscott, Mass.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, GEORGE FRANCIS SEVER, New York.

ON AMERICAN YEAR-BOOK.

EDWARD CALDWELL, New York.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

EDWARD B. ROSA, Washington, D C.
JOHN B. WHITEHEAD, Baltimore, Md

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

JOHN J. CARTY, New York.
CALVERT TOWNLEY, New York.

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE, G. P. O., Perth, Australia
HORACE FIELD PARSHALL, Salisbury House, London Wall, E. C., London.
L.A. HERDT, McGill University, Montreal Que.
CLARE F. BEAMES, Bangalore, Mysore Province, India.
WILLIAM G. T. GOODMAN, Adelaide, South Australia.
ROBERT JULIAN SCOTT, Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.
RICHARD O. HEINRICH, Genest-str. 5, Schoeneberg, Berlin, Germany.

LIST OF SECTIONS.

Revised to June 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Atlanta............Jan. 19, '04	A. M. Schoen	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	Fred. P. Valentine.	G. A. Rodenbaeck, 84 State St , Boston, Mass
Chicago..................1893	J. G. Wray.	
Cleveland.........Sept. 27, '07	E. J. Edwards.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	A. B. Morrison, 817 Nelson Street, Ft. Wayne, Ind.
Indianapolis-Lafayette. Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca.............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N Y
Los Angeles.......May 19, '08	O. H. Ensign.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Lynn.............Aug 22, '11	E. E Boyer	I. H. Sclater, General Electric Co., Lynn, Mass
Madison..........Jan 8, '09	J. N. Cadby.	H. B. Sanford. Univ. of Wisconsin, Madison, Wis.
Mexico.. ....Dec. 13, '07	W. H. Fiske.	H. S. Foley, Apartado 124 Bis., Mexico, D. F.
Milwaukee........Feb. 11, '10	F. A. Vaughan	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota ....Apr. 7, '02	Chas. L. Pillsbury.	Leo H. Cooper, 805 Metropolitan Life Bldg., Minneapolis, Minn.
Philadelphia.......Feb 18 '03	H. Clyde Snook.	H. F. Sanville, 1326 Chestnut St, Philadelphia, Pa.
Pittsburg..........Oct. 13, '02	K C. Randall.	E. L. Farrar, G. E. Co., Oliver Bldg., Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	W. C. Smith.	W. W. Lewis, General Electric Company Pittsfield, Mass.
Portland, Ore......May 18, '09	H. R. Wakeman.	G. P. Nock, Pacific Tel. and Tel. Co., Portland, Ore.
San Francisco.....Dec. 23, '04	S B. Charters	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady.......Jan 26, '03	E. B. Merriam.	C. Lichtenberg, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	J. D. Ross.	M. T. Crawford, Seattle-Tacoma Power Co., Seattle, Wash.
St. Louis..........Jan. 14, '03	Joseph A. Osborn.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo.
Toledo............June 3, '07	George E. Kirk	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto...........Sept. 30, '03	A. L. Mudge	W. E. Young, 212 King St., West, Toronto, Ont.
Urbana...........Nov. 25, '02	E. H. Waldo	F. G. Willson, University of Illinois, Urbana, Ill.
Vancouver........Aug 22, '11	F. D. Nims	E. M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D C..Apr. 9, '03	**Earl Wheeler.**	H. C. Eddy, Interstate Commerce Commission, Washington, D. C.

Total, 28

LIST OF BRANCHES.

Revised to June 1, 1912.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov. 12, '09	C. E. Greene.	M. L. Johnson, College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Hulse, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	W. Fryberg.	R. L. Walsh, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	Harrison S. Sweet	Daniel M. Wise, Bucknell University, Lewisburg, Pa
California, Univ. of..Feb. 9, '12	Charles Grunsky.	C. I. Kephart, University of California.
Case School, Cleveland Jan. 8, '09		
Cincinnati, Univ. of..Apr. 10, '08	W. H. Jefferson.	Oscar Plueddemann, 3133 Hackberry Street, Cincinnati, O.
Colorado State Agricultural College.......Feb. 11, '10	D. E. Byerley.	A. A. Catlin, 626 So. Meldrum St., Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	Harry McKinney.	Seizo Uyeda, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	F. A. Fish.	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	L. J. Kieser.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan. 10, '08	B. F. Hillebrandt	W. C. Lane, Kansas State Agric. Col., Manhattan Kan.
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of................Oct. 14, '10	W. H. Jaegle.	J. H. Gaiser, 341 Harrison Ave., Lexington, Ky.
Lafayette College....Apr. 5, '12	F. W. Mane.	W. O. Hay, Jr. Lafayette College, Easton, Pa.
Lehigh University....Oct. 15, '02	W. J. Dugan.	E. F. Weaver, Lehigh University, South Bethlehem, Pa.
Lewis Institute.......Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	Benjamin Haskell	John E. Ash. University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	Ward F. Davidson	Edward A. Roeser, Univ. of Michigan, Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	J. Glen Luther.	J. A .Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	Robin Beach.	Clayton W. Work, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts. Feb. 11, '10	E. P. Speer.	W. H. Graham, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
Ohio Northern Univ. Feb. 9, '12	F. M. Billhimer.	J. E. Wineland, Ohio Northern University, Ada, Ohio.
Ohio State Univ......Dec. 20, '02	R. E. Kinkead.	L. W. Frost, Ohio State University, Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.....Oct. 13, '11	W. E. Dolde.	H. P. Cook, Oklahoma Agricultural and Mechanical College, Stillwater, Okla
Oregon State Agr. Col Mar. 24, '08	H. Belknap.	W. R. Varner, Oregon St. Agric. College, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02		
Purdue Univ.........Jan. 26, '03	C. F. Harding.	A. L. Topping, Purdue University, Lafayette, Ind.
Rensselaer Poly. Inst. Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Rose Polytechnic Inst. Nov. 10, '11	Jerry H. Service, Jr.	David W. Jones, 911 North 8th Street, Terre Haute, Ind.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.......Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.......Feb. 14, '08	J. A. Correll	N. H. Brown, University of Texas, Austin, Tex.
Throop Poly. Inst....Oct. 14, '10	Frank C. Miller.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal.
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	O. Krupp, 65 North Bend St., Burlington, Vt.
Virginia, Univ. of...Feb. 9, '12	Walter S. Rodman	
Wash., State Coll. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Irwin L. Cheney.	P. S. Stevens, Washington University, St. Louis, Mo.
Worcester Poly. Inst. Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass
Yale University......Oct. 13, '11	E. C. Willard, Jr.	M. R. Wibberley, 361 Elm Street, New Haven, Conn.

Total, 43

PROCEEDINGS

of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

SECTION II

Papers, Discussions and Reports

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DISCUSSION ON "INDUCTION MACHINES FOR HEAVY SINGLE-PHASE MOTOR SERVICE," "ELECTRICAL OPERATION OF THE WEST JERSEY SEASHORE RAILROAD," "ANALYSIS OF ELECTRIFICATION." CHICAGO, ILL., JUNE 28, 1911. (SEE PROCEEDINGS FOR APRIL, 1911, JUNE, 1911, AUGUST, 1911.)

(Subject to final revision for the Transactions.)

Frank J. Sprague: I have a somewhat proprietary and professional interest in Chicago. It is true, as the President has said, that my inaugural address in 1892 was on the coming developments in electric railways. That was some nineteen years ago. It was the same year when Charles J. Van Depoele, that ingenious, persistent and hard working pioneer in the electric railway field, gave up his earthly activities, and left his name, his influence and the record of his early work, but also a continuing loss to a new development and to a great industry.

This morning I glanced over the address which I made at that time, and were I to write a paper at the present moment upon this particular subject I would in few particulars change the conclusions at which I then arrived. Those were early days in electric railroading, and possibly I may be permitted at this date to quote one or two of my remarks illustrating my then prophecy, if you please to call it so, and my general attitude. That was only three or four years after the beginning of the commercial development of the trolley system, when, on account of the active development of that field and the ambitious hopes of electrical engineers and manufacturers, the electric railways of this country, city, urban, suburban, interurban and trunk lines, were in a few years to be converted to electric lines, and the knell of the steam locomotive sounded. It seemed to me at that time necessary to indicate the possible order of development of electric railways, and to utter a word of warning against undue optimism. Speaking of trunk line operation, I said: "Turning now to the greater powers, we must not confuse the terms "large powered" and "trunk line" work. They are two statements which I think will need no corroboration. If we had a continuous train movement completely occupying a track system, there can be no question but that its operation from a central source by electricity would be more economical than if operated by steam locomotives. So, too if a large number of units in reasonable proximity are moved, and the starting and stopping so regulated that the total demand on the central stations is fairly continuous and equal, then there is no question as to economy of electric propulsion as compared to steam. On the other hand, the operation of a single unit or very few units over a long distance would be so uneconomical and afford so small a return on the investment required as to make it prohibitory. Between these two lies the condition of operation where steam and electricity meet on planes of equality; as the number of trains decreases steam operation is more economical, as the number increases electricity must be preferred."

I further said: "It seems to me the growth of electric railways will proceed something in this order:—First, the street systems in the various towns, then connecting lines between adjacent towns, following the line of highways, then along connecting lines, either on the track of existing steam lines, or growing bolder, on exclusive rights of way. Then will come suburban traffic on a large scale, and freight transfer systems, and finally the more ambitious project of trunk line service under limiting conditions such as I will specify. It has been very properly said that a man will make his first long ride on electric railways by transferring from one town system to another, through connecting links, rather than on individual roads."

As it was my privilege at that early date to here record convictions which time has confirmed, there is another reason why I should have a kindly feeling for Chicago. Ten years after the inauguration of the pioneer Richmond trolley road a combination of circumstances led me to develop the multiple unit train control system, and I sought, at my own expense, to make a demonstration of that system on the then steam operated Manhattan Elevated railroad lines in New York, because the system promised radical advantages in economy of operation and increase in capacity. Despite many attempts, I was not able to make it there, and it was not until the South Side Elevated Railroad in this City, having passed through the hands of a receiver, found it necessary to change its motive power to electricity, that I found an opportunity to demonstrate the value of my invention of multiple unit control. It was due to Chicago engineers, Messrs. Sargeant and Lundy, who gave me their personal confidence, and to the courage of the capitalists back of the railroad, that in Chicago was made the first beginning of that which has become now so vital and essential to all electric railway operation on a large scale.

Now, Mr. President, I presume Mr. Wood's paper has been presented in its order?

The President: Yes, all three papers have been presented.

Frank J. Sprague: I do not feel confident to discuss Mr. Alexanderson's paper. He has made an interesting suggestion for the use of alternating current with a split-phase device, by means of which, with a single phase supply, he can make use of the polyphase motor. As experimental developments are in a very active state of progress, I think it is useless to prophecy what the possible results will be, but rather to wait and see what the outcome is.

In considering present problems, let us note for a moment what the conditions were at the time I made my inaugural address. All work was then practically being done with direct current, with limiting potentials of from 400 to 600 volts. The direct current motor was being rapidly developed, but single phase and polyphase motors were almost unknown. The static transformer was just coming into use, and the motor generator had been introduced but was not meeting with any widespread applications. The rotary converter had been invented but was almost an unknown piece of apparatus.

The limitations, however, of direct current at the pressures then common had become manifest. I had already, some three years earlier, advocated much higher direct current potentials, which have been since materialized; and in the early days of electric lighting, when one of the local manufacturing interests was embarking in the developing of alternating current apparatus, I believe I was the first independent engineer to recommend to another corporation the necessity of alternating current transmission to supplement its direct current operations.

It has been stated that history is repeating itself, and that electric railway equipment will, therefore, follow a certain definite alternating current development. Quite probably history will in many ways repeat itself, but if so it will be along lines which are not exclusive, for that is not its usual habit.

Somewhat necessarily, it seems to me, there has arisen a difference between electrical engineers as to railway systems which has given rise almost to the establishment of certain cults, and the zeal of the advocates of each partakes something of religious fervor. Now the problem we have to face is very much like many others in the use of electric power. It is to generate and transmit energy with the maximum of reliability, convenience and economy, and then to use it in motors variously applied; the one thing which differentiates the railway problem from all others is that the motors are on moving vehicles, and hence the grouping is variable, both in amounts and distances from the source of supply, while the total power is oftentimes small compared with the distance over which it is distributed.

Were any particular feature of the problem to be discussed there would probably be little difference among engineers as to the best solution. For example, all would agree that the central power plant should be situated where the cost of construction and the supply of fuel and water, labor and incidentals would insure the maximum of reliability and economy; that such a plant should be equipped with turbines direct coupled to three phase generators, wound for a comparatively moderate potential, and operated on closed circuits. Transmission would likewise be by polyphase currents at potentials determined by local conditions, to which end, and for the providing of the proper potential at the railroad, static transformers would be the necessary adjunct at both ends of the transmission line.

They would also probably agree that provision must be made for supplying the railroad in such a manner that it could be sectionalized, both as to divisions and tracks, so that the entire system would not be disorganized and thrown out of operation because of accident to any part.

They would agree also that there is a variety of service to provide for—freight, through passenger and local and suburban services; and that some trains should be pulled by single locomotives, others by double headers, yet others by locomotives both at the head and in the body of the train, and still others operated by motor cars grouped into trains on the multiple unit system.

Again, they would agree that current must be supplied to the trains along the right of way by working conductors in the form of an overhead trolley, variously erected and supported, available for single or polyphase currents at all practical potentials and for direct current at much higher potentials than have been common, or in the form of a third rail, protected or otherwise, available only for direct current.

Coming now to motors, it would also generally be agreed that the polyphase motor has the highest weight-efficiency, and that the direct current stands next in order, while the single phase has less output per unit of weight than either of its rivals; that the polyphase motor requires besides the track two conductors, and has the limitation of constant speed, while the other two types of motors require but one conductor beside the track, and have variable speed characteristics. Both of the alternating current motors ordinarily would require static transformers on the locomotives, while for direct current operation rotary transformers or motor-generators must be used at the substations.

Also, in the United States, there are three alternating current frequencies in extended use, namely, twenty-five, forty and sixty cycles, and where a single-phase motor is used frequencies from 25 down to 15 only are practically usable, the latter being more favorable.

Taking all these various factors into account, the problem must necessarily be a compromise in settlement; but despite this fact, and the further fact that the supply of power for railway operation is but a fraction of that used for all purposes, many would differentiate the railway supply from all others and set up a standard for universal acceptance.

It is unfortunate that in so doing there is a disposition in many quarters to base comparisons upon arbitrary limits of development on the one hand, and unquestioning acceptance of results accomplished or promised on the other, despite the fact that engineers, the world over, when brought face to face with specific problems oftentimes arrive at different conclusions. It seems to me that this is a wrong attitude, and that the duty of the electrical engineer is to encourage the fullest development by every known system, so that he may, with open mind and in the full light of actual experience, decide for the best whenever he has to consider any specific problem, even if when some other is presented his decision may be different.

In short, while there are many things that can be or are standardized there are some things which in my judgment can not now, and perhaps never will be made universally exclusive.

As Chairman of the Railway Committee, therefore, it has seemed to me that we should have arrived by this time to a discussion of Steam *vs.* Electric operation, based upon known operating facts and known construction costs, whatever the system used; and I repeat the time is inopportune and the occasion unwise that brings up at present any discussion which attempts a present settlement of the question of this or that predominant system. To this end, I have continually urged the getting from existing corporations actual facts, not promises or predictions, but facts concerning operation in that same detail that we have for the operation of urban or interurban railways.

We have been passing through an experimental stage of exceeding importance and far reaching consequence. The single-phase development promised much, it has disappointed much; it has been watched with a great deal of interest with a desire to know the results. It received its first impulse in this country on the interurban railways, and the history of that development has been interesting. All installations here have been put in through the instrumentality of two companies. I am not entirely certain of my statistics, but of the six or eight single-phase equipments put in with the apparatus of one of these companies, one only is now in operation. Some of these roads have gone into the hands of receivers, as it is true other roads under other systems have gone, and direct current has taken the place of alternating current operation. Notably, there is the case of the Baltimore, Washington and Annapolis road, probably one of the largest and most influential examples of interurban operation which we have in this country, and one of the most suggestive.

Now we have in operation a number of roads on a sufficient scale to get operative facts, let them be what they are. We have in New York three great terminal equipments. There is the New York Central and Harlem, operating at 650 volts on direct current supplied from an under-contact rail, and the New York, New Haven and Hartford, operating from Woodlawn to 42nd St. on direct current, and from Woodlawn north and east to Stamford by the single-phase, with an overhead trolley. Both of these have a considerable mileage of tracks. There is also the terminal operation of the Pennsylvania Railroad into New York City, which is on the direct current system, and the extensive Long Island Railroad development, which may be considered essentially a suburban system, also aggregating a very considerable mileage. Then there is the West Jersey and Seashore Railroad, running from Camden to Atlantic City, a distance of about eighty miles, with a trackage of one hundred and fifty miles, converted a few years ago from a steam line into a direct-current system.

Whether from fear of the Interstate Commerce Commission, or the demands of commuters, or because of certain unsettled conditions, or because possibly the circumstances are such that they do not care to have it impressed upon them that electrification might take place elsewhere under other conditions—railway officials have manifested a great reluctance to give the actual facts as to costs of operation, not predictions of what may be sometime, but what, under the existing exigencies of the service are the actual facts at the present time.

Of course, this operation is dependent on a number of factors, and the first is the cost of creating power, of which we have heard so much—in short, the operation of the power station. This is a factor which has become pretty well known in its characteristics, its cost, reliability and what not, on all ordinary electrical work, but which for some reason or other, has been kept with extraordinary secrecy from the ordinary knowledge of interested engineers where it applies to these larger trunk line installations. I do not intend to unduly criticise that attitude, although I think it is a mistaken one.

During the past year, therefore, I have bent my energies to find out if it were not possible by some means, through some channel, to bring out the facts, so far as they can be brought out, for comparison; because, after all, it is facts we want, not theory. Comparison of power house operation has for sometime, it is true, been privately made in great detail, and for mutual advantage, at the Port Morris, the Long Island and the Westville power houses. Later there has been added the Jersey City and Marion plants. Up to December, 1910, those were the only ones of these large railway power houses (I should have included the Interborough of Manhattan) which were making direct comparisons. I believe that in February last the New Haven consented to coöperate in making these private comparisons. But, really, why should not all, and freely, make public the facts?

Mr. Wood's paper was originally compiled for the purposes of presenting to the general manager of his division the facts contained therein. The Railway Committee of the Institute asked Mr. Wood if he would not request, as a courtesy and privilege, his general manager to allow the actual facts of the cost of operation of that railroad, as contained in the paper, to be presented at this meeting. Mr. Wood was fortunate enough to get the consent of his superior official to that publication. It has, I believe, set an example which other railroads must follow in time. Mr. Wood's action not only is highly creditable to his capacity and his persuasive powers, but the presentation of facts which he has made will prove in the end one of the most important, because of its initiation in getting at results, which has ever been laid before this Institute. I think that the thanks of the Railway Committee and the members in general are due to Mr. Wood for having been able to present these facts as he has, and to have done it with such perfect frankness.

I will not hold our electrical engineers entirely responsible for the lack of information. They are, after all, the servants of the railway officials, and railway officials, sometimes I think mistakenly, sometimes rightly, think perhaps the time is not ripe, the extent of operation not sufficient to justify them in making public the actual facts of the operation. But it seems to me, after all, we as engineers can differentiate the various factors that go to make up these reports; and when a railway official gets that opinion into his head then we may be trusted with some degree of confidence in dealing with the facts when laid before us.

Mr. Wood's paper has some features to which I wish to call particular attention. The time of installation, occupied only seven months, a most creditable performance. The power-house report for 1910 makes the cost per kw-hr. .542 cents, a creditable result under the circumstances. In passing, it is of interest to note that at the Jersey City and Marion power stations, although there is a difference in year 1910 of nearly one hundred per cent in the basic cost of coal, there is a difference of only eight per cent in the cost per kw-hr., and the actual cost is less with the station which used the higher priced coal, but not for that reason. The transmission efficiencies from power house bus-bar to substation bus-bar on the Westville line increased from 72 per cent in 1907 to nearly 82 per cent in 1910. That makes the power cost at present 0.542 cents per kw-hr. at the central station and 0.646 cents at the substation; and the cost of operating the substations based on this output is 0.108 cents per kw-hr.

The total cost of operation per car mile in 1910 averaged something over 18 cents, varying from a little over 12 cents to nearly 25 cents per car mile, a variation which is affected by frequency of service, density of movement, and the use of current for lighting, heating and various other purposes. While there was this variation of nearly 13 cents in cost per car mile, the cost of power delivered varied less than 3 cents. Out of the 18 or 19 cents average total cost per car mile of operation, of which only 3⅓ cents represented the cost of power, the cost of the sub-station attendance, maintenance and upkeep was three per cent of the total. The upkeep of the high tension transmission line was something over $4.00 and the third rail $6.50 per mile, while the upkeep of the trolley was six times that of the third rail per mile.

Coming now to Mr. Murray's paper, it is somewhat difficult for me to treat it with the thoroughness which its voluminous character and its wide dissemination would ordinarily be expected to require. What was hoped for, and is needed more than all else, is that presentation of actual construction and operating costs so vital to any intelligent consideration of the subject of steam railroad electrification by any means whatever—not a special plea for a particular system, no matter how ardent its advocate may feel in its behalf.

I doubt not that among the many engineers of occasional conservative tendencies—the natural result of some years' experience in spending one's own and one's client's money in industrial development, and sometimes seeking an acceptable excuse for a dearth of dividends in times of increased cost of living—I am included (to borrow Mr. Murray's description) among those "who claim some recognition in the field of railroad engineering," and who believe that the time has not yet come, if indeed it will ever come, when the electrical engineer, in his broader responsibility, can say that there is but one system of electrification adequate to meet all the varied problems of railroading.

Certainly such cannot be said, with any degree of lasting authority, at the present moment; one might as well say that we have reached the limit of the tireless activities of the myriads of workers in the electrical fields, and that the curtain has fallen on new discoveries and inventions. Equally mistaken would be the claim that all railroads are ready to be electrified, or on the other hand that none are, or that a hard and fast line of demarcation can be drawn between those which should and those which should not consider a change of motive power.

The author has presented many interesting isolated facts, some of undoubted value, and varied such presentations with a plentitude of drawings from the all-embracing and constantly accumulating records of the New Haven engineering department. But one looks in vain for some correlated and definite facts as to the costs of construction and costs of operation, either individual or comparative. Even the simplest facts as to cost of overhead installation, of locomotives and motor cars, or costs of power production and distribution, or of locomotive, and motor car repairs and upkeep are not given.

I will take only a few moments to touch on one or two points in Mr. Murray's paper. There is here presented, what? Not the single-phase system, as ordinarily understood, but what I may call the author's system. I think it can be all found in his two earlier papers. What are the characteristics of the system? Single-phase transmissions at a potential limited by the requirements of the trolley wire, from central stations equipped with generators built with variable voltages and operated with grounded circuits; the abolition of step-up and step-down transformers, thus giving up the absolute and necessary freedom of determining economically the potential of long distance transmission from a central station; a potential of 11,000, volts or higher on a trolley line in contiguous territories, but with entire freedom to change that potential to something different on remote lines; the abolition of the single-phase, 25-cycle motor, and the substitution therefor, as a possibility in the near or the dim future, of a single-phase induction motor, or in lieu of that the much criticized direct current motor supplied by a mercury rectifier or its equivalent. Furthermore, we have 25 cycles as the preferred frequency. In this last, Mr. Murray is somewhat at variance with the practical experience and recommendations of some others. We find the German, Swiss, Italian and Swedish engineers, and one of the great manufacturers of this country, who supplied the apparatus for the New Haven road, recommending, where alternating current is to be used, about fifteen cycles as the proper standard for trunk line operation, while many of our prominent engineers in this country, men of wide experience and ability, and prominent in this Society, endorse 25 cycles. We find eminent engineers abroad recommending polyphase apparatus entirely, others prefer single-phase, and here we have some who believe in developing the direct current to its logical limits so that what it can accomplish may be safely and fairly measured in comparison.

Mr. Murray says, " We have made the system work, now let us make it pay." After you have made a system reliable, and within its possible economy workable, the way to make it pay is to get traffic, and also to extend the use of the system to an engine division. Mr. McHenry, Vice-President of the New Haven Road, is quoted as saying that, after all, if the passenger service can be operated by electricity, every wheel on a division ought to be turned by electricity; and he points out the important fact that the schedules of the freight operation can be so arranged as not to materially add to the burden of maximum demand on the central and substations. It seems to me that this latter day suggestion to operate every wheel of a division by electricity is very familiar. When the New Haven system was put in I said that if there is any reason for the adoption of this system on the New Haven road, even within the limits of the electric zone, the operation should be extended to every wheel, that passenger trains, multiple unit and through, and freight trains should be operated electrically; in short, one should be able to get the diversity factor on a railroad as well as elsewhere.

But I am going one step further. I am one of those who have a sort of growing belief that that diversity factor should be extended, and those who went yesterday afternoon to the magnificent Commonwealth Edison Company stations, and saw single generators of a continuous capacity two or three times the average power consumed the year round on the West Jersey line, and know something about the diversity of service on these plants, must realize, it seems to me, that the day of individualizing the railroad as we are in the habit of doing will pass, and that its demand for power, with increasing reliability of central station operation, will be met by great central stations connected up together, and further, that these central stations will be engaged not only in supplying electricity to railroads, but for every purpose for which electricity can be used within the radius of their operation. The New York Central and the New Haven roads could be supplied today, and supplied with less money, without one dollar of investment in central stations, by a general station of the capacity, size and system of operation of that of the Commonwealth Edison Company.

This statement has a bearing directly on the situation in Chicago at the present time. Here are more than a score of railroads entering the City, and an attempt to issue a mandatory decree by the Council that there must be electrification of these lines within the city limits within a certain time. I am opposed to mandatory legislation of that kind, but when electrification does come it will be for the engineers in charge to determine it. Then they should keep one problem in mind: How can the maximum benefit be obtained with the minimum of burden to the railroad and the community? That will mean a consolidation of power plants, so that the current will be supplied from a limited number of well situated distributing centers which will provide not only power for the railroads, but for everything else within the radius of their action. I think that this means polyphase transmission, and quite likely direct current distribution.

We have had one or two criticisms of the storage battery. Most people do not know why the battery was put in on the New York Central railroad, of whose Committee on Electrification I was a member. It was installed on the advice of every member of the Commission, because of the then absolute necessity for the fullest measure of insurance, not because we expected to lower the kw. cost much. We cut out part of our generating equipment, and spent $1,000,000 for batteries, and increased the then reliability of the plant from a practical point of operation by a large margin. There have been times when that insurance was worth a good deal of money. There are in New York and Chicago two of the greatest central power stations for general supply in this country. I believe there are not less than 40 to 45 batteries in the New York City plant, and a correspondingly large capacity in storage batteries in the Chicago plant; and if you ask the managers of these stations what is the use of the battery, they will tell you that it is not for the economical production of power, but for the insurance which the battery affords. I do not know to what extent storage batteries may be used on railroads in the future. The increase in the general reliability of central stations and in the limits of rotary converters are such that sometimes we will not need a battery, but if a battery is to be used, remember that it is for insurance; do not go on the mistaken idea that it is put in to materially lower the cost of power, all things considered. When it is used it is applicable to direct current distribution, and not to single-phase distribution except by the introduction of moving apparatus of the full required substation capacity.

The time is so limited that some notes I have made I shall pass by for the present, but I wish to impress on you all my conviction, and I believe I have some right to express a conviction in a matter to which I have given twenty-five years, that the battle should be between steam and electricity and not between systems. I say, " God speed " to advance by whatever system, be it single-phase, polyphase or direct current, but when the merits of systems are discussed, I for one will always stand absolutely opposed to fatuous comparisons which accept all the promises of the one and deny the possibilities of the others.

Edwin B. Katte: I have not had an opportunity to read Mr. Wood's paper with the care that is necessary to discuss such a paper in detail. The real value of his paper is as an incentive to draw out similar operating information, and I will be glad to coöperate with the Railroad Committee in an endeavor to obtain more such data. I was sorry to note on the very first page that there would be no comparison with the cost of steam operation. We do not yet know the relative cost of steam and electric operation on trunk line railroads.

Among the very interesting points which attracted my attention was the comparison of the third-rail and the trolley systems. Mr. Sprague has already called attention to the fact that the trolley per mile costs six times as much to maintain as the third-rail. Again, in Table 8, we find that the detentions due to all third-rail troubles were twenty-eight minutes, and to the trolley troubles they were one thousand nine hundred and twenty minutes. At another point the first cost is given, and it is interesting to note that the cost of the overhead trolley is almost exactly the same as the cost of the third rail.

L. C. Fritch: I do not expect to talk to you this morning from the standpoint of an electrical engineer, but rather from the standpoint of the steam railroad engineer. I am very glad now, as a member of this Railroad Committee, that I did not prepare a paper for discussion at this meeting, seeing how Mr. Murray's paper is being criticized, but I will say that I did prepare a paper on the subject of the electrification of steam railroads as applied to terminals, but it was so proelectric, that when the railroad men received it it was suppressed. One President of a railroad said—" You are too enthusiastic on this subject, you have too much electricity in your system, and your views are too advanced. But from the investigation I have made so far I have reached this conclusion—" that there is work in transportation in heavy trunk line service that the steam locomotive cannot perform, but there is no work in transportation on heavy trunk line service that an electric locomotive cannot perform more efficiently than the steam locomotives. While I am not as narrow minded, I think, as some railroad men, I am certain it is possible to demonstrate that phase of the question when considering the application of electricity to heavy trunk line service. It seems to me that railroad men are making a mistake in endeavoring to ward off something that is inevitable. The recent development of the Mallet type of locomotive, in my opinion, is the dying gasp of the steam railroad men to maintain steam as a motive power on railroads. When we consider the Mallet type engine, weighing 615,000 lb., total weight, the weight on drivers 550,000 lb., with a tractive effort of 137,500 lb., and a ratio of pounds on drivers and tractive effort of 4, and then take the Pennsylvania railroad type electric locomotive of the passenger type, total weight of 332,000 lb., weight on drivers 207,000 lb., and tractive effort of 69,300 lb., and then take into consideration the overload capacity and the ratio of driver weight to tractive effort per pound, of 3, I think the argument is in favor of the electric locomotive. The railroads in this country have spent millions of dollars in grade reduction, line revision, and tunnel excavation, which, if it had been spent for electrification of these lines, in my opinion, in many cases it would have shown more economical results.

Now, as to the question in Chicago, the situation here is peculiar to itself and I am not altogether agreed with some of the statements made here this morning, that it is not a question of the systems, it is a question as between steam and electricity. It is true, it should be a battle between steam and electricity, but the question of the system must be established. As long as the system is not established, you are simply furnishing ammunition for those who do not desire to electrify.

The situation here in Chicago is this: We have some twenty-five trunk lines in Chicago. There is an interchange of freight traffic between all of them; the locomotives of one company go into the yards of every other company. Now, if one company should adopt one system, and another company adopt another system, it is readily seen how impossible the operation would be. I am an advocate of a universal system, or a system of systems that will be mutually interchangeable, and unless you make progress along that line, electrification is not going to make much advance in heavy trunk line service. In New York, of course, the situation is different from what it is here, but there is no reason why this question cannot be solved, and I think that instead of electrical engineers having a battle of systems, they ought to get together and devise a system or systems that will be mutually interchangeable.

Considering further the Chicago situation, which I think will be of interest to you, it has always appeared to me that the question has been approached from the wrong angle. It has always been a question of—Will it pay? While, of course, the financial question is the all-important question, yet there are instances in this city where electrification on certain branches of service will be justified, not as a whole, perhaps but an initial installation will pay, and that will demonstrate whether an extension of electrification will be justified. That, in my opinion, is the proper way to investigate the question here. There has recently been a Commission appointed to investigate the question in Chicago, and I do not think it will be difficult to write that Committee's report now, because statements have been made that it will cost $250,000,000 to electrify the railroads in Chicago. I do not agree with that statement. I think a sum half that amount would meet all the objectionable features of steam operation in Chicago today. The situation here demands not only electrification, an investigation into the matter of electrification, but a revision of the entire terminal situation. The railroad tracks in Chicago were laid principally as though shot out of a gun, without much system or relation to each other. What should be done, in my opinion, is that the railroads, as a whole, should get together and revise their terminals, and in my opinion, they should electrify them within certain reasonable limits; that common entrances should be provided and a group of passenger stations, with a joint entrance which could be electrified. If the freight terminals were made joint freight terminals, and all interchange traffic that has no business within the Chicago business district kept out of it, the local business could be handled in a much more simple manner than it is handled today and lend itself more readily to electrification.

There is one point that Mr. Murray has brought out, which I consider very valuable at this time, and that is the question of the electrification of switching terminals. In my opinion, that is one of the most important matters that has been brought out in these papers. He has shown that there is a possibility of a saving of at least thirty per cent in the number of units of switching locomotives. Now, take one railroad in Chicago having forty-five switch engines, a reduction of 30 per cent, would mean fifteen locomotives, and taking these locomotives at an average cost of $10,000 a year per locomotive, that would mean $150,000, which capitalized would mean $3,000,000. That will go a long ways toward electrifying a switching terminal. These are matters which we should bring out and develop, and wherever you raise the question of electrification, in railroad circles, you will be met with the statement that never yet has a large freight terminal been electrified, that it is not possible, and is impracticable in every sense. I do not believe that. I believe that in yard operation it is possible with overhead construction, using either direct current or alternating current, such as Mr. Murray figured out, and that it can be built for from $1500 to $2000 for single track per mile. It is not a question of the number of tracks. If you have a yard with fifty tracks, you can span these tracks, and that will remove all the objections to the third-rail or surface conductor which, of course, would be almost inadmissable in some instances. It would be possible to use a lower voltage in the yard that out on the main lines, where trolleys would be perfectly practicable.

J. L. Woodbridge: Mr. Murray in his paper states that storage batteries for trunk line electrification are not economical. He admits that a battery will permit more economical generation of power, but states that this increase in economy is offset by the increased output required (presumably to supply battery losses) and the cost of battery maintenance; and concludes his observations on this subject with the remark " It is of interest to note the passing of the storage battery theory; at least in as far as its application to trunk line conditions is concerned."

I desire to take issue with Mr. Murray on this point. So sweeping a statement would seem to call for a presentation of the facts and arguments upon which it is based. As it stands, it appears to be merely the expression of his own unsupported personal opinion. Without knowing the source from which it was derived, a comprehensive reply is impossible; but I would like to offer a few remarks on the other side of the question, and present a few actual facts in support of my position.

Inasmuch as Mr. Murray is evidently looking at the commercial, rather than the technical side of the question, I shall confine my remarks to that aspect of the matter. The question is, therefore, can a storage battery be so applied to trunk line electrification and so operated that the increase of economy in the generation (and possibly the transmission) of electrical energy will more than offset the cost of battery losses, battery maintenance and interest on increased investment, if any. I believe that in many, if not most, cases of trunk line electrification a complete analysis of the problem would show that a storage battery, properly adapted to meet the conditions and controlled to produce maximum economy, will be a profitable investment. In support of this position I would submit a few actual facts.

About three years ago, the Chicago City Railway Company entered into a contract with the Commonwealth Edison Company for the purpose of power. The details of this contract have been published, and are well known. It provides for the payment of a unit price per kw-hr. plus a service charge of $15 per kw. per year for the maximum peak, this peak being the average of the maximum one hour peaks of any three consecutive days. In order to reduce this service charge, the Railway Company, who already had one battery in service at 77th Street, installed another much larger battery at their Plymouth substation. As a result of the operation of these two installations, the saving in the power bills after deducting maintenance, operating expenses, rent, insurance, taxes, etc., is sufficient to pay 12 per cent on the investment. Now it will, of course, be contended that this result is due to the peculiar terms of the power contract, which penalizes the purchaser for peak loads to such an extent that the battery installation becomes a commercial proposition. This is very true, but if this power contract is fair and equitable to both parties in all its terms and conditions (and of this there can be no doubt in view of the standing and ability of the men who drew it up), if the terms of sale are logically based upon the conditions of power production, and the prices are truly proportionate to costs, then the battery investment would be equally profitable if the Chicago City Railway Company were developing its own power. In fact, it should be more so, since the terms of the power contract undoubtedly make it necessary for the Railway Company to discharge its batteries on peak loads on some occasions when there would be no economic advantage in doing this. If the Chicago City Railway Company were developing its own power it would be possible to reduce the amount of work which the battery is now called upon to do, and thus reduce the cost of maintenance.

The Chicago City Railway is not, of course, a case of trunk line electrification, but it will doubtless be conceded that trunk line service is still more favorable to the storage battery, in view of the smaller number and heavier demand of the train units, and the more irregular and intermittent character of the load.

The economy arising from the presence of a storage battery in connection with an electric system may be effected in two different ways.

First, a careful analysis of the cost of producing power under the various load conditions will show that not every kw-hr. is produced at the same cost, but that this cost varies widely at different times of the day, and under different conditions of operation. In general, the power produced below the average load line at a steady rate, for many consecutive hours, is developed at minimum cost, while the power produced for the short peaks above the average line, is produced at maximum cost. The difference between these two costs of power is actually much greater than many engineers are apt to realize. To develop energy at the minimum cost, and store it in a battery, to be again delivered to the system under conditions when the cost of developing the power directly would be a maximum is one method of deriving economical results from the operation of the battery.

The second way in which a storage battery can effect improved economy of operation is by its mere presence on the system as a reservoir of energy ready to deliver its output at a moment's warning under any unforeseen conditions of demand or power supply. The mere fact that such a reservoir is at hand, even though it be seldom called upon, will permit a more economical operation of boiler and engine room than would be possible if some other form of generating apparatus, such as boilers, engines and generators, must be kept in readiness for emergency service. The batteries installed in connection with the New York Central electrification are handled in this way.

A review of recent progress in storage battery engineering, and recent development in automatic controlling apparatus, will reveal a tendency to limit more carefully the operation of batteries to the particular class of work for which they are especially adapted, and to eliminate a large amount of battery work which does not make for economy. It is not economical for a storage battery to take *all* the peaks above and below a given average load line. Much of this class of work, which has heretofore been thrown on storage batteries where they have been installed, would be more economically handled by the generating apparatus. This fact is being more and more clearly recognized, and automatic controlling apparatus has been developed to discriminate between the different classes of fluctuations in such a way that only those peaks and fluctuations which can be economically carried by the battery, are referred to it. This means that the size of the battery may in some cases be reduced, the first cost decreased and the maintenance charge lessened. In any case the efficiency of operation is improved.

The use of storage batteries for stand-by service has also assumed greater prominence in recent years, and while this use is largely found in electric lighting systems, it is occasionally applied to railway work. The operation of the battery in connection with the Baltimore Tunnel electrification is in some ways an example of this class of service. The Baltimore and Ohio Railroad Co. has recently entered into a contract for the purchase of power from the Consolidated Gas, Electric Light and Power Company, under the terms of which the cost of power is increased by peaks and fluctuations above certain specified limits. The battery is operated to prevent the power demand from exceeding these limits. Under ordinary load conditions the battery is merely floating on the line, and is prevented from charging or discharging when such work would not have any effect in reducing the cost of power. When, however, the demand exceeds the limit set, the battery discharges, taking all load fluctuations above this limit. This operation, which may be called stand-by regulating service, is produced automatically by controlling apparatus recently installed. The result is that the battery is called upon to do only such work as is commercially economical. This is another instance in which the terms of the power contract between the user and the producer of power make the operation of a storage battery commercially economical. The terms of this contract are the result of a careful analysis of all the conditions of power production and utilization, this analysis being equally applicable if the operating company were producing its own power.

It may be interesting to note that in neither of the cases cited above is it a part of the battery's function to regulate the momentary fluctuations of load for the improvement of the lighting service of the company which is producing the power. The momentary fluctuations in both cases are ordinarily allowed to fall on the power company's system. Refinement of voltage regulation, which in some situations is the motive for the installation of a battery, is not called for in these two examples and the argument for the use of storage batteries in these cases rests on commercial economy only.

Dugald C. Jackson: The electrification project of the New York, New Haven & Hartford Railroad, for handling trains entering and leaving New York, has been a center of interest to all engineers having electric railroad relations; and the courage and vigor with which the engineering staff of that road attacked the problem of designing, constructing and adapting a then substantially untried alternating current system to meet the needs of an active steam railroad traffic has been a matter of satisfaction and congratulation to all. The accomplishment that has been reached in four or five years is remarkable, and is a monument to the fidelity and skill of the engineering staff which carried it out.

The drawings which accompany Mr. Murray's paper give concrete evidence of some of the work done and some of the difficulties which had to be overcome to make the working of the system a success. I speak of difficulties—they obviously were tremendous, and when faced in the course of work must at times have seemed nearly insuperable. Their spikes and claws appear relatively few and harmless when viewed in the retrospect afforded by this paper, but the credit to the engineers whose courage, foresight and ability wrought this result, should not be diminished. When we admire the courage evidenced by the New Haven Railroad organization, by the adoption and installation in service of its Stamford-Woodlawn system of electrification, and their skill in overcoming the appalling difficulties which faced them, we must also acknowledge that the adoption of 11,000-volt trolley construction in the wet and difficult conditions of the Hoosac Tunnel proves that their courage remains unbroken.

There is no longer any question of the physical ability of electric motive power to cope successfully with all of the problems of trunk line, suburban or terminal service, and with a reliability excelling the service by steam motive power. The only possible exception may be that of the railroad yard, but any one who goes to Mr. Murray's little yard—little to be sure, but effective—over which he now has wires, cannot but be impressed with the simplicity of the situation there. I have not yet had an opportunity to look at Mr. Murray's switching locomotive, but from what he tells me it must be remarkable for activity and perfection in operation. Not only that, but we now have the proof that electric motive power is satisfactory for the work of moving trains in trunk line service, (as we have heretofore had proof of its adaptability in suburban and terminal service), and this with a reliability obtained which perhaps excels and, at least fully equals the records of steam motive power. These proofs have been made in a few years. Having made these proofs in relatively few years, we are bound to see yet better results as more experience is obtained. Well built electric machines are acknowledged to be among the most reliable machines made by man, and the substitution of electric for steam motive power removes the least reliable part of the motive power of the railroads, that is, the engine and boiler, from the road, and establishes them in larger and better perfected units located in stationary power stations where they can be properly inspected, supervised and cared for.

The physical success of electric motive power has been abundantly proved in trunk line, suburban and terminal service, for single-phase, polyphase, and direct current installations, in this country and Europe. It is undeniable that several Swiss roads have made a success of electrification, but perhaps they are too small to be compared with some of the great trunk lines in this country, and I will not go into a discussion of them. The Valtellina road was one of the earliest steam railroads to convert to electric service, and its electric service has been successfully maintained for years. Various other Italian roads give evidence of success. The London-Brighton installation in England has sufficiently proved its justification. Neither is physical success deniable in the installations at the Cascade Tunnel of the Great Northern Railroad, the St. Clair Tunnel of the Grand Trunk Railroad, the relatively new Detroit Tunnel of the Michigan Central Railroad, the West Jersey and Seashore Line of the Pennsylvania Railroad which Mr. Wood described, the lines of the Long Island Railroad, the New York Terminal of the New York Central Railroad, which Mr. Katte discussed, the Stamford-Woodlawn zone of the New York, New Haven & Hartford railroad, which Mr. Murray described, and the relatively new New York Terminal of the Pennsylvania Railroad, and other important installations in the United States.

It is being urged in some quarters that electrification of additional lines or terminals on a large scale ought not to be pressed forward, on the ground that engineering in this branch lacks standards. The data contained in the papers presented this morning, it seems to me, prove the substantial baselessness of that assertion, notwithstanding the fact that one dealt with an alternating current installation and one dealt with a direct current installation. The baselessness of that assertion is equally proved by the standards of electrical construction and apparatus of the New York, New Haven & Hartford Railroad, the New York Central & Hudson River Railroad, and the Pennsylvania Railroad. The fact that electrification may be made by means of either single-phase, polyphase, or direct current does not signify lack of standards, but is a patent of the ability of electric power to meet every requirement when the system adapted for particular service is selected and installed with engineering skill. In a situation such as exists here in Chicago, it would as Mr. Fritch suggests be criminal for the important roads to adopt systems which are not freely interchangeable. Some minor road may have a different system on account of not coming into the main systems, but the equipment of all important roads entering a place like Chicago must be completely interchangeable. This however may be accomplished, and involves harmony in engineering plans to bring it about. The prime point is, that electrification allows a choice of motive power which will most effectually serve the purposes of the particular terminal conditions.

It would be palpably absurd to assert that no standards exist in steam locomotive practice because Atlantic type, Pacific type, Mallet articulated and other types of locomotives are in common service in different parts of the country, where different conditions are to be met. I presume, in fact, that electric motive power has come nearer uniformity in standards, young as electric service is, than practice with steam motive power has yet attained. The flexibility of electrical equipment is illustrated by the capability of the New Haven motors and controlling devices to operate successfully and alternatively over the New Haven's own lines with its 11,000 volt alternating current delivered to the contact shoe by trolley wire, and over the New York Central's lines with its 700-volt direct current delivered to the contact shoe by third-rail. An argument against electrification on the ground that standards and conditions of interchangeability are not being or cannot be provided where they are needed is obviously untenable.

The only open question about electrification, *i.e.*, whether the improved service which is inherent with it can be established and provided without enhancing the present cost of service, is not answered in Mr. Murray's paper, or wholly in Mr. Wood's paper; and rumors regarding the fiscal achievements of the important electrification projects operating in various parts of the world are not sufficient bases to afford conclusions. It is obvious that steam operated trunk lines of light traffic and unimportant terminals are not at the present time reasonable candidates for electrification, and the open question, therefore, relates to important terminal centers and to trunk lines and suburban lines with reasonably dense traffic. A number of good clues to the answer to this question are already available from papers which have been read before this Institute. Good clues are further available in the continued satisfaction given by the electric operation of certain of the Italian, Swiss, and French railways (some of them doing both freight and passenger business), besides the two or three in England, the reports that have as yet been made public regarding the fiscal success of the West Jersey & Seashore and Long Island Railroad electrifications, the St. Clair Tunnel installation, and perhaps others, in addition to the very persuasive example put forward by the New York, New Haven & Hartford railroad in planning extensions of their existing electrification, with which they have had several years experience and with which they appear well satisfied.

It is to be further observed that fiscal comparisons between the New Haven electrification and its well systematized steam locomotive service probably cannot yet be flatly made. The electrification has only recently emerged triumphant from the pains of a developing system to a point where Mr. Murray is prepared to say that it operates under commercial conditions. Somewhat the same is true of the New York Central & Hudson River Railroad installation. Indeed, both of these installations are operated under the expensive conditions imposed by reconstruction work going on at the New York terminal, which must temporarily add cost to the handling of trains. Under all these obstacles, electrification seems to have "made good."

N. W. Storer: There are a few points which stand out in Mr. Wood's paper that I should like to refer to briefly:

First. The excellent showing made in the extremely small number of detentions due to the motive power, as compared with those due to other causes. The fact that the detentions due to motive power and weather conditions together amount to only 8.38 per cent of the total number, shows a reliability of the service, which would be increased but little if all of the delays due to motive power were wiped out completely. It shows that until the delays due to general traffic conditions can be substantially reduced, it is useless to go to an enormous expense to reduce the already almost negligible delays, due to motive power.

Second. The data showing gradual decrease in the cost of power, indicating what can be done by scientific management, is certainly most encouraging. I discussed this matter with Mr. Wood, who stated that he had had some of his own men take charge of the power house and substations operation, with an immediate reduction in the cost of operation as the result. The rotary converters in the substation were operating practically all of the time in the earlier days of operation, and much of the time unnecessarily. They found it entirely possible to shut them down a good part of the time, and in this way reduced the light load losses, thus making a surprising difference in the power consumption.

Third. There are some points in connection with the operation of trains also tending to increase the power consumption which should be noted, one of which is the number of brake shoes that are worn out. In the year 1910 we note that there were 6300 brake shoes changed. It would be interesting to learn how many kw-hrs. were required to wear them out. One cannot help calling attention to the advantage in introducing the coasting time clock or some similar meter system, which will tend to increase the amount of coasting time, and therefore to reduce the speed at which the brakes are applied, and finally decrease the wear on the brake shoes and the power consumption. If brakes are applied when the cars are running at a speed of 50 miles per hour they must absorb practically four times as much energy as they would at 25 miles per hour, and it is probable that four times as much brake shoe will be worn off. A reduction in the speed at which the brakes are applied in ordinary operation will therefore effect a great reduction in the number of brake shoes, as well as in the amount of power consumed.

In discussing this paper, I think some of the speakers have gone out of their way to make unfavorable comparisons between the costs of maintenance of trolley and third rail. The advocates of any overhead trolley system might well be alarmed if the costs of maintenance given in this paper were characteristic of all the overhead trolleys, but fortunately such is not the case.

The idea that we gather from the paper is that multiple unit trains with wheel trolleys, operating under certain conditions, at high speed, over a rigid cross-span construction, are very destructive to the overhead system. Anyone who is at all familiar with the cost of maintenance of the overhead trolley system of an ordinary interurban line would know at once that the cost of $440 per mile, as given in this paper, is extremely abnormal. Wheel trolleys are made at the present time that will operate safely at high speeds on a good overhead construction. The roller pantagraph, as well as the sliding pantagraph, will also operate well. The roller is now used quite extensively on the Pacific Coast, and with success. The use of such a trolley would unquestionably practically wipe out the cost of maintenance of the overhead trolley wire, as well as some of the numerous delays noted. The cost of the maintenance of the third rail is very reasonable—in fact, is lower than most third rail systems, because it is of the simplest form used. It is a good, substantial third-rail construction, but it is not protected, and this fact decreases the cost of maintenance.

I am very sorry Mr. Katte did not give us the cost of maintenance of the New York Central third rail system. This is practically the best protected system at present in use, and some information in regard to the cost of maintenance would be very illuminating. I do not recall that any figures have ever been published in regard to this, and I am sure that such information would be very valuable to many members of the Institute.

There are a few points in Mr. Murray's paper which may be discussed.

It seems to me that if the events of the last two years have shown anything, they have shown the unwisdom of making such dire prophecies as were freely made at the time the single-phase system was installed on the New York, New Haven & Hartford Railroad. It seems to me that any system which has so many advantages and possibilities as the single-phase system should have the united efforts of all engineers concerned in developing them at the earliest possible moment.

Now in regard to this question of standardization. I believe that both Mr. Murray and Mr. Fritch are right—we must have some degree of standardization before the great work of electrifying railways goes much further, and this can only be accomplished by getting together. I do not mean to say by this that we must immediately unite on the single-phase system for all future work, but I mean that an effort must be made to get the most out of each system that is proposed. I wish it understood in this connection that I am not prejudiced in favor of the single-phase system. I am personally engaged in the development of designs and the manufacture of apparatus for operating on all of the different railway systems, and in that way am making every effort to make the best out of each one of them. I have advocated in the past, and am still advocating, the single-phase system for use in certain places, but have never ceased to believe that the apparatus designed for the 600-volt direct current system is the standard for reliability. Having had a wide experience with all systems, I feel that I can give an unbiased opinion. All I wish is to see the best system adopted. We must have a certain amount of standardization, especially for cities like Chicago, where the motive power must necessarily be interchangeable on all of the roads, and we engineers should get together very soon and get something settled.

I want to emphasize the point Mr. Murray has made in regard to the advantage of electric locomotives for switching service—a service in which it has been used comparatively little. It is ideal for that class of work, and certainly will be used a great deal in the near future.

At the time the passenger locomotives now in use on the New Haven Railway were built, both the railway company and the manufacturers of the locomotives were severely criticized because of the weight, and the fact that it was necessary to use two locomotives for hauling the heavier trains. This matter of course has been explained many times. I mention it only to call attention to the improvements which have been made since the first installation, in the capacity and weight of locomotives. In my discussion of Mr. Murray's paper at Toronto, I mentioned the new type of locomotive which has been built for the New Haven Company. It has quite radical electrical, as well as mechanical, features. The general view of this locomotive is given in Fig. 1, Plate 1. This is simply a sample locomotive of the double Mallet Type, but it has been properly christened "The Colonial Type". Each driving axle is operated by a pair of motors, which are mounted rigidly on the frame of the locomotive, directly above the axle, and are geared to a quill surrounding the axle. The quill drive is exactly the same as shown for the 071 locomotive in Mr. Murray's paper, but there is only one gear required where two are necessary for the single large motor shown on the 071 locomotive. It is a strange thing that for single-phase work at any rate two motors of a certain total capacity can be made lighter and cheaper than a single large motor of the same capacity. We have therefore applied two small motors here, where on the 071 locomotive one motor is used. This design has the following advantages:

First. Coupling two small motors permanently in series gives the effect of a high voltage motor. This reduces the sizes of cables and control losses on the locomotive.

Second. Only one gear is required where two would be necessary with the single large motor developing the same tractive effort. Both pinions on the small motors drive the same gear. This reduces the weight very materially, and also the expense of installation.

Third. The small motors are much better adapted to the space between the wheels than a large motor, because the only way to increase the capacity of the motor is to increase its diameter, and when it becomes necessary to use twin gears for a large motor, the space available between the wheels for the motor itself is very much reduced, and consequently the diameter and weight must be greatly increased. It must be noted that the total number of running parts in the motors, *i.e.*, commutator bars, brushes, brush holders, poles, etc., are practically the same whether one motor is used or two. There will therefore be no more possibilities for trouble developing in the two motors than there are for one, and cost of repairing the small motor is very much less than making similar repairs on the large motor.

Fourth. The control equipment itself, on account of having a higher voltage, is simpler and cheaper.

The weight of the locomotive as shown is 116½ tons, and will develop continuously a tractive effort of 12,000 lbs. at 35 to 40 miles per hour. It will also be used for hauling heavy passenger trains up to speeds of 50 miles per hour. The weight as given includes the complete steam boiler, water tank, and direct current control equipment. With these parts removed, the weight would scarcely exceed 108 tons, showing that a very substantial gain has been made in the design of the single-phase electric locomotives, since the first ones were introduced. This machine will haul the heaviest train on the New Haven Railroad, whether it be a 1500-ton freight or an 800-ton passenger train, and will develop a good speed with either.

The mechanical design of the locomotive is also quite novel. The two middle pairs of drivers form a rigid wheel base, and an outer driver with its pony axle forms another rigid wheel base, which leads the locomotive. The deep plate frames are entirely outside of the axles, and are connected at the ends by heavy bumper girders, the bump being transmitted to them through the leading truck frame. The entire construction of the locomotive lends itself to lightness, as well as strength, and we expect to hear some excellent reports on the performance of this locomotive.

John W. Lieb, Jr.: Considerable has been said about the importance of power house operation in connection with the electrification of trunk line railroads, and I hope I may add a mite to the discussion in that particular direction. The power station companies, companies distributing light and power in our big cities, such as the companies in Chicago, New York, and similar communities, are, I need hardly say, desirous of getting that business. We are not very much interested in the question whether the roads operate at three-phase or single-phase, or by the direct-current system, provided we can get the current supply to them. That is selfish, I will admit, but it is also business, and it is in the line of the economical development of electric power. We would, however, urge on this question of standardization, that it is of immense importance to the companies embarking on this question, to be able to exchange current with the local large supply source, and therefore, I was much pleased with Mr. Murray's plea for 25-cycle generation, even in the case of alternating current systems.

Now, we who are engaged in the lighting and power distribution business believe that we can be of immense assistance in hastening this electrification problem, because one of the great difficulties is the immense investments that are required in accomplishing this electrification; but if the terminal companies and the railroad companies can feel that they can obtain their power supply at a cost certainly not to exceed what it would cost them, and save that enormous element of investment, which the local lighting and power companies are ready to supply, we believe that we have contributed at least one important element toward hastening this consummation.

I need hardly make a plea here for combination service, as between railway service and lighting and power service, but I will say this—that a careful study of the times of peak load between lighting and power systems shows the immense economical advantages which may accrue through a combination of these services, not only in the enormous saving of investment which will come even by so small a difference of maximum loads at peaks, of a difference in time of fifteen minutes between the railway and lighting peaks, which in the case of power plants of 100,000 kw. or more may represent a saving in investment of 1,000 or 1,500 kw., but also in the very greatly improved load factor which results from this diversity factor, and we all know what an important place the load factor has in the central station power cost economy.

Something has been said about storage batteries, and I would like to say a word as to that, and that is of the vital necessity which the storage battery is to-day in this question of absolutely certain continuity of service. I am frank to say that I believe our very large power systems, certainly those for the distribution of light and power, have a record for continuity of service which they would not have, and it would be practically impossible to maintain such a record, without the assistance of the storage battery.

It is true that the conditions of battery operation have greatly changed in the past few years. We have departed from the idea and necessity for using the battery for large current output, for continuous use, or the idea that in order to keep batteries in live condition they must be charged and discharged at minimum intervals, say once a week, or several times a month. We are satisfied now that we can obtain and maintain batteries in perfectly healthy condition by using them simply as a reserve, as an insurance, and for this purpose their value is simply inestimable. They play today an immense part in central station economy, and by having the railroads install their own batteries to assist in the distribution end especially, of course, with direct current,

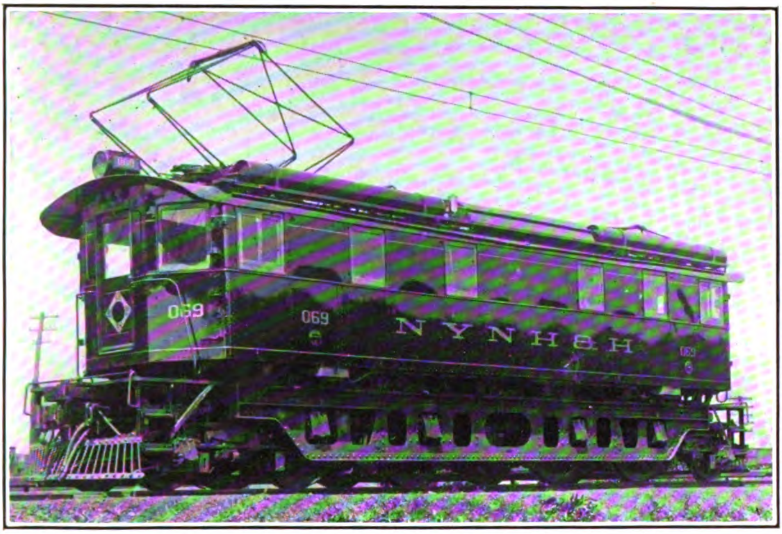
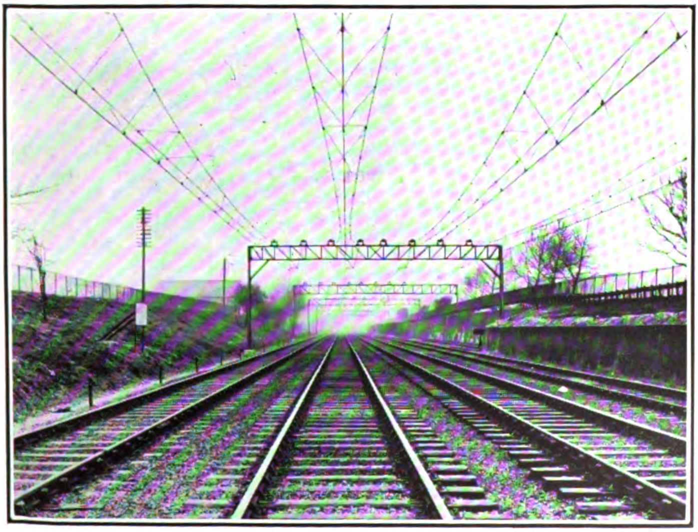
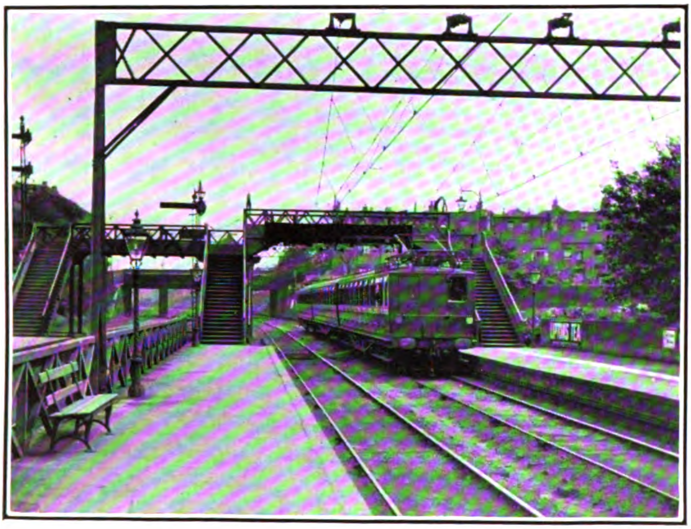


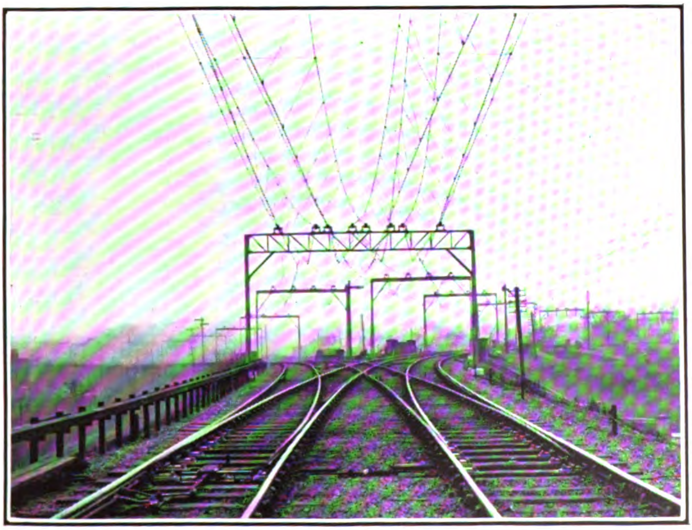
FIG. 1 [STORER]



WANDSWORTH COMMON [DAWSON]



WANDSWORTH ROAD [DAWSON]



LEIGHAM JUNCTION [DAWSON]

they will be able to bear with the local lighting companies the incidental economies and advantages which come from reducing peak demands.

I would like to make, therefore, an urgent plea for a settlement on this question of combined service, believing that, first, it will assist in the economical solution and hastening of this electrification problem, and secondly, because of the enormous advantages which will accrue to both the railway and lighting companies in the adoption of combined service.

In this particular field, I cannot hesitate for the moment it takes, to give the praise which should be due to this great institution, the Commonwealth Edison Company, in having been the leaders in this enormously important field, and having made practical demonstrations on a large scale of the advantages which were likely to accrue, and which do certainly accrue, from this combination of service.

Charles. F. Scott: I would like for a moment to compare the difference in the discussion of the railway question in the Institute a few years ago with the discussion to-day. At the Great Barrington meeting, held nine years ago, there were many railway papers presented, and many prominent engineers took part in the discussion of these papers. I have run through the proceedings of that meeting very carefully, and the one urgent question in the minds of all was this—How can we operate electric railways by supplying alternating current directly to the car or locomotive? And the solution which they thought apparently impossible was—" Where shall we get a motor? If we had a single phase alternating current motor the difficulty would be solved." A few months later was presented the paper proposing that motor. About five years later one of the most important railways in the country began operations under certain handicaps. The work was undertaken very quickly, the locomotives had to be designed and put in operation in a short time, there was not available the ten years which direct current had for its development, and they had the handicap of operating both by alternating current and direct current; nor was the motor the whole problem, for the line question, the switch question, and the generator question, came in as even more important than the motor in practical operation.

We have heard with great interest of very interesting tests which were made here in Chicago on switches, on a system on which short circuits were rare, where the high-tension circuits are protected in cables underground. On the New Haven system, with 100 miles of trolley wire in railway service, where short circuits were more or less frequent, with a generating capacity greater than in the tests here made, the solution had to be worked out while the railway was operating. That is one example of the kind of problems that come up in large work in a new field. Now we know that the alternating current will operate satisfactorily, and it is a choice between systems. The manufacturing companies have done their part, they put hundreds of thousands of dollars into this development. The problem has been crystallizing into a matter of operation. What are the operating conditions? What are the things which cannot be determined in the designing room or testing room of the manufacturing companies? The papers, such as are now presented, give records and facts which present to all the problem which must be worked out, jointly, by manufacturers, consulting engineers and railway men—what are the conditions of operation and how can they be met and by what system? Do we want to standardize? Yes, we want to standardize as rapidly as we are sure of our ground, but we want to leave open the opportunities for development. Several of these developments were suggested this morning—a mercury rectifier, the induction motor operating from single phase, and these, I believe, have been the only things looked forward to in the future. But these, as well as the single-phase motor, will all operate from the single-phase trolley, so that the single-phase system, as a general railway system leaves them open for adoption in the future. It is significant that Mr. Murray, who is in the best position to know the difficulties in operating a single-phase road, is the man who is loudest in its praise.

Frank J. Sprague: I have heard the few remarks made by Mr. Storer and also the statement by Mr. Murray. I have avoided all reference to overhead or third-rail matters in yards, advocating neither the one or the other in the brief remarks I have made. The overhead construction shown by Mr. Murray is equally applicable for direct current or single-phase current operation, so if that in his opinion is the determining feature, I am glad of it.

Mr. Storer intimated that in passing comments on Mr. Wood's paper I made some invidious comparison between the upkeep of the third-rail and the overhead structure on the West Jersey & Seashore road, and that I might have taken the trouble to speak of the local conditions. I do not know what the local conditions are. I took the paper and gave the relative costs of third-rail or overhead trolley upkeep simply as incidental facts.

E. F. Alexanderson: There is one phase of the subject of trunk electrification to which I wish to call attention. Mr. Murray has referred to the same by making the statement that the system was laid out with the consideration in view that the traction work at some later time would be done by induction motors.

Whether it should be considered as unfortunate or not, it is a fact that the development of the alternating current motive power for railroad, has been in opposite direction to the corresponding development for industrial and mining enterprises. The alternating current distribution system is admittedly unrivaled and the use of the same is supported by the undisputed superiority of the induction motor for all purposes where such motors can be used. From the fundamental system of power supply by induction motors has grown up a number of special developments like the single phase induction motor, the single phase commutator motor, and the polyphase commutator motor. A campaign has been going on for several years for exploiting inventions along these lines, and to define the special requirement where an induction motor cannot be used to advantage in order to find application for special apparatus in order to meet those requirements. All those machines are expensive and objectionable in many ways compared with the induction motor, but the field that must be covered by such machines is small compared with the general application of induction motors, so that the use of such machines is not considered as an argument against alternating current systems.

In alternating current practice the development has been the opposite. The most difficult problem has been attempted to begin with and has been furthermore complicated by the requirement that the a-c. equipment should also be operative on direct current. The result is that the a-c. traction system has been largely discredited. If the development had been the opposite, if the three-phase induction motor had gained in an established right in the railway field, if then the single-phase distribution had superseded the three phase, yet maintaining the constant speed induction motor, and finally the commutator had been introduced for such special conditions of traction where the variable speed characteristics are valuable enough to warrant a higher expenditure, then the various problems of railroad electrification might have appeared in a quite different light.

In view of Mr. Murray's statement, it is gratifying to see that he has already considered the possibility that a development of the motive equipment might be started over again on a more sound basis. It might be premature to predict that all the traction work under Mr. Murray's supervision could be carried out by induction motors, but I feel confident that the larger part of it could, with a greatly reduced expenditure both in first cost of equipment and in maintenance.

Philip Dawson (by letter): I entirely agree with the paragraph in the commencement of Mr. Murray's paper, in which he states that the religion of his paper is to preach the doctrine of universal use of the single phase current on trunk lines and roads inclusive of terminal territory, as applied to freight and passenger operation.

The experience I now have in connection with the electrification of the Brighton Railway which is equivalent to the equipment of over 60 miles of single track, (a large portion of which has been running since the beginning of 1909) has convinced me that there is now no longer any doubt that the single phase system is at least as good as the continuous current system for operating suburban traffic requiring rapid acceleration, and with short distances between stopping places. This having been demonstrated by actual experience, there could be no doubt that for the electrification of any of the main line railways, the only system which could be considered is the single-phase one. No one I think denies that for long distance work the single phase is the only solution. The contention of those, who through thick and thin uphold the continuous current, is, that for short distance work the continuous current is far superior to alternating, and that therefore it should be used for this class of service, and that when long distance work becomes necessary, the single phase system should be installed in addition to it.

It may be interesting to know that we have had practically no troubles or serious inconvenience of any kind since we started service in 1909 and that with the multiple unit trains and with the average annual mileage per motor coach, including all our spares, and those which are being overhauled, was last year, over 58,000 miles.

Our average speed with stations three-quarters of a mile apart, is 25 miles per hour. The line consists of nothing but curves and gradients and at the start, out of Victoria station, we have a gradient of one in 64 for over a quarter of a mile.

Besides this we have five sections where overhead conductors are connected to earth which thus seriously interfere with acceleration; one of these dead sections being just at the foot of the gradient out of Victoria station. Our average acceleration throughout the whole period of acceleration from 0 to about 35 miles an hour is one mile per hour per second.

We wished we could increase this by increasing the size of motors and the capacity of the power station, experience, however, has shown that the acceleration I originally selected is sufficient, and the increase in traffic since electrification started has been over 150 per cent and it is still increasing. This is a very important fact particularly if we consider that the South London line is intersected and paralleled by a very large number of electric tramways, that the saving in time is only about 10 minutes, and that the fares on the electric railways are nearly double those on the tramways.

In connection with the experience which has been obtained with continuous current electric railways and single phase current electric railways, there is no one who has greater right to speak than Mr. Wittefeld, the Chief Engineer of the Prussian Government Railways. He has constructed and operated both continuous current and single phase railways. The continuous current is one in Berlin going to Lichterfelde and worked by most up-to-date continuous current apparatus and having very heavy suburban traffic. The single-phase line is that at Hamburg both having now been worked for some years, and Mr. Wittefeld is the only engineer and railway official I know who has this dual experience at his disposal.

His letter addressed to me in connection with my paper before the Institute of Civil Engineers states:

"Your satisfactory experience regarding single phase traction for working surburban lines, entirely agree with ours on the Blanknese line. It can no longer be doubted, in accordance with my own personal experience, that for suburban electrification the single phase system is at least as good as the continuous current system. The experimental results for long distance traffic with very heavy as well as fast trains on the section Dessau Bitterfeld on this system have been most satisfactory. The large electric locomotives driven by connecting rods have surpassed all expectations. It is now my unshakable decision that the single phase system with the experience we have now gained, is the only system which can generally be used for electrification of main line railways, no experienced railway engineer, who wishes to be considered far sighted, can, I think, come to any other conclusion."

Besides the above, Dr. Wyssling who was head of the Swiss Commission appointed to investigate the question of railway electrification, also wrote to me in connection with my paper. He said, "That according to his conclusions and that of his committee the single phase system is the one which is most suitable for heavy railway electrification, because the transmission and contact system is the simplest, because the great variations in speed possible, and because it is the cheapest to install."

I am sending three views of the line which may be of interest. (See Plates I and II.)

W. N. Smith (by letter): As matters are now in the trunk line electrification field, installations upon a large scale are so few, that Mr. Murray is in the unique position of having had more practical experience than almost any other engineer in his special field—which gives him a distinct advantage over his critics, both past and present.

This installation in general is an illustration of the principle, that in any new departure the engineer can expect to learn a vast deal about structural and operative details as he goes along and at the same time can be confident of being generally upheld by results, in the decisions he had to make when planning the work.

It may be well to keep in the foreground Mr. Murray's definition of a trunk line. About a year ago, before the New York Railway Club, he defined his conception of a trunk line as "A line connecting large cities which are separated at some considerable distance. The portion of a trunk line which lies in the immediate vicinity and the outlying districts of those cities will carry upon it a suburban traffic."

Without criticising this conception, it might easily be implied from Mr. Murray's present paper that he considered as trunk lines only such roads as might be in the same class with the New Haven, namely, a main trunk of from two to four or six tracks, with numerous single and double track branches or net works and a heavy suburban service. It is a well known fact that some of the most important railroad lines connecting the large cities of the country are single track lines, particularly in the less densely settled portion of the country, though in some sections the most important roads are making progress in double tracking. Nevertheless, there are many roads that are not likely to double track for at least one more generation, and yet are, in the general opinion of themselves and the public, entitled to be called trunk lines, as is further borne out by the fact that all rolling equipment upon steam railroads, whether main lines, branches or otherwise, is interchangeable; and so far as structural considerations are concerned, trunk line conditions are usually conceived to include branches or side lines, whether located so as to be fit for electrification, or not; as well as the main arteries of traffic which have already reached or may ultimately reach that density of traffic which determines the economic suitability of electrification. The Spokane & Inland Empire Line, for instance, is more than 120 miles long and though it does not connect Spokane with any city even approaching Spokane in size, it is still fitted for handling standard trunk line equipment and actually does handle railroad freight trains of a respectable size with the system of electrification advocated by Mr. Murray, though at lower trolley voltage. Its peculiar situation, as respects cost of providing power for operating, is said to have favored the adoption of electric motive power, as distinct from considerations of traffic density, thus making it a special case. It would not be called a main trunk line, for instance, in comparison with the Northern Pacific; but the adoption of that equipment which is most suitable for long lines with heavy trains brings it into the trunk line class, so far as electrification is concerned.

To summarize, it seems to me that the accomplishment of trunk line electrification is broadly determined, first of all, by the general characteristics of railroad rolling stock used for transportation, and in a secondary degree by geographical location.

Mr. Murray states that the criterion of financial return is "how much it costs to produce the necessary tractive effort" in the several types of locomotive mentioned. The writer believes that this statement of the problem, while it appeals to one's engineering sense as probably true, is still so vague as not to carry conviction. Rightly or wrongly, the ton-mile or the car-mile are the units most commonly used for comparing transportation performances—as is well shown by Mr. Murray's own data. It seems to me that until some new unit is invented which will more correctly express the desired relationships, the ton-mile or car-mile should be used as explicitly as possible in making such comparisons. Annual reports of the largest steam railroad systems commonly include a great deal of statistical information that is or can be referred to a ton-mile basis for comparison, and the present Interstate Commerce classification enables the compilation of a good deal of interesting information regarding the various costs of train performances per ton-mile, if one will take the trouble to dig it out of a comprehensive report.

I am impressed with the magnificent performance of the New Haven system as regards the small amount of train delays; but it should not be forgotten that this particular system has four tracks and an arrangement of feeder section switches on the anchor bridges which enables sections to be readily isolated in case of trouble, thus preventing many delays providing the trouble is discovered soon enough. It is very doubtful whether any single track line with an equivalent train mileage per mile of single track could exhibit such a clean record, as the difficulty of reaching and remedying trouble without interfering with train service on a single track is vastly greater than on a 4-track system. The high grade insulation which Mr. Murray advises to be used as the cheapest means of securing satisfactory trunk line operation, is even more necessary on a single track than on a 4-track trunk line; and this is as true of strain insulators as of the straight line insulators. Mechanical sufficiency in every part is equally important for the same reason, and the various details mentioned by Mr. Murray as constituting distinct mechanical improvements, should therefore be all the more carefully followed in single track line construction.

Referring to Mr. Murray's remarks on storage batteries for trunk line electrification, he is undoubtedly correct for trunk line electrifications approaching the magnitude of the New Haven Railroad. But cases have arisen in the past, and probably will from time to time in the near future, where the use of a storage battery offers some economic advantages. Here, again, the Spokane & Inland Railway furnishes an example of trunk line electrification under special conditions which made a battery adjunct advisable, even with the extra conversion losses from continuous back to alternating current when discharging. The fact that the current for this system is generated by water power will go far to explain the reason for the adoption of the battery in this instance.

In view of the numerous failures of the early types of storage battery in street car service during the early development of electric traction, it may at first appear idle to some, to even consider the possibilities of the storage battery for direct propulsion of cars in trunk line work, but the gradual improvement in reliability that the lead battery has developed in electric vehicle service; the development of the nickel-iron-potash battery by Mr. Edison; and the successful application of both these batteries to light railway work during the past year, in New York City, Philadelphia and Washington, together with the successful experiments in the operation of branch lines of the Long Island Railroad and the Erie Railroad, each of which now has a battery car in operation, all indicate that we are not yet at the end of our resources as to the choice of an electric propulsion system for at least some types of steam railroad service. The developments of the past year have been on a small scale, but are most encouraging, and indicate that if both electric tramway and steam railroad engineers are willing to reconsider their previous conceptions as to design and weight of car bodies, anti-friction journal bearings, motor capacities, gear drives, and battery maintenance, in connection with the possibilities which battery car propulsion offers in the production or purchase of electric power at a high load factor, (which minimizes power-station or sub-station investment and operating expense, or enables the purchase of off-peak power at minimum rates), they will be enabled to view the economics of heavy electric traction from a new angle.

This applies more especially at the present time to electric trunk-line branch service; the next step will be in the direction of battery traction for suburban service at moderate speeds.

The more recent successes of storage battery traction have been largely due to the fact, that the cars thus far constructed have been practically built around the battery, and are of very light construction, with anti-friction bearings, thus reducing both the tons to be transported and the pounds per ton resistance of the car journals. The writer believes that the problems to be solved in connection with the development of storage battery traction for trunk line branch and suburban service are much more of a mechanical nature than electrical, and reduce ultimately to the question of how light it will be possible to construct a car, suitable for operation on steam railroad tracks, that shall be regarded as sufficiently strong to insure its own stability and the safety of the passengers against all shocks that can reasonably be expected, and can carry enough battery for economical operation in the service it is desired to handle.

These questions will be settled by the judgment of railroad mechanical experts and will doubtless require much experimental working out; nevertheless, I believe that the field for exercise of ingenuity in this line will be cultivated, though it may be a few years before it has acquired the status now enjoyed by the several typical systems involving working conductors. The fact that power in any necessary quantity can now be purchased at the lowest possible rates for charging battery cars during those periods of the twenty-four hours when they are most likely to be idle, together with the entire abolition of working conductors for the tracks, which eliminates the question of interchangeability of different working conductor systems, constitute arguments that will be likely to appeal to steam railroad men. Such possibilities are, of course, predicated upon the assumption that the storage battery of the future will prove to be as reliable and subject to no more depreciation per car mile than modern types of motors and generators. Should this development eventually come into being, and should steam railroad officers permit themselves to utilize lighter car bodies, we will then have available one more method for utilizing electrical apparatus to supersede the steam locomotive, in some situations, at a lower first cost than is possible with the present systems of instantaneous transmission of railway power.

Railroad electrification is at the present time much desired by the public at more than one large terminal. Whatever system of electrification be followed, the probability is that the suburban service of almost any railroad would be the first to be electrified, thus resulting for a time in a mixed steam and electric system. The initial electrical equipment must, therefore, operate in some degree interchangeably with the existing steam equipment, and all the circumstances surrounding steam operation must be given consideration as affecting the first cost, operation, and general durability of the proposed electrical equipment.

Mr. Murray has fulfilled the engineer's function of getting superlatively good results under certain difficult conditions with the electrical apparatus now available for such work. I must confess, however, to a degree of caution when it comes to declaring the state of the art at this time as so complete, that all work in the immediate future should be based upon present practice, even on the remarkable showing made by the New Haven Railroad installation. I shall not be surprised if, by the time that railroads in general are able to pay for electrification on a large scale, some methods less costly, both as to investment and daily operation, will have been devised for accomplishing the desired results, especially in those terminal situations where the need for steam railroad electrification is now most pressing.

B. F. Wood: In view of the limited time at my disposal I shall confine my remarks to the suggestion made by Mr. Lieb that power should be purchased from power companies rather than generated by the railroad companies at their own plants.

By reference to the table showing Cost of Construction it will be noted that the investment in power station and transmission line is nearly a quarter of a million dollars. With this amount included the net earnings during the year 1910 were sufficient to make a return on the total investment for electrification of about 8¼ per cent. If power could have been purchased at rates prevailing in Chicago for such service, the same net earnings would have shown a return of nearly 9¼ per cent on the lesser investment necessary; showing conclusively that the power station is not earning the average rate of return.

At the time of the electrification of the West Jersey & Seashore Railroad it was not possible to purchase power for such operation and it was therefore necessary for the railroad company to build its own power station.

Again, the rates for power in some cases have not been based upon the cost of furnishing the service but have been fixed with relationship to the charges for other service differing in character and in a good many cases such rates have been prohibitive.

The responsibility, therefore, for the railroad companies building power stations rests largely with the power companies and if they are to take over this business they must fix their rates on a basis that will give a return on investment necessary for such service and not on the average cost of power.

C. P. Steinmetz (by letter): Mr. Murray's paper appears to me very interesting and valuable for the complete information which it gives on the practical experience of a number of years operation of a section of a trunk line railway, electrified by the single phase alternating current system.

Especially important appears to me the conclusion which Mr. Murray reached as the result of actual experience of several years successful operation, that 25 cycles is the proper frequency for railway electrification. This entirely agrees with my opinion, which I expressed here at a previous occasion some years ago: " If the single phase commutator motor can not be designed and operated at 25 cycles, it can have no future and no right of existence." No odd frequency, as 15 cycles, or 8 cycles, can be seriously considered, especially after the unfortunate previous experience. In some special instance, a railway section isolated from all sources of electric power supply, some odd frequency as 15 cycles may appear to have some advantage without any immediate disadvantage, just as 40 cycles appeared advantageous for mill work; but sooner or later the disadvantage of the odd frequency will become apparent, and it would be fortunate if then it would only mean scrapping the odd equipment, as is being done in southern 40-cycle cotton mills, and if the odd frequency has not spread so as to be irredeemable, as 50 cycles in Southern California and 40 cycles in the upper Hudson River development.

John B. Taylor (by letter): Under the heading of Power House, Mr. Murray points out the advantages of employing three-phase generators rather than single phase, even though the bulk of the energy is supplied to a single phase trolley system. This naturally results in unbalanced voltage which is a point of greater or less importance depending on the amount and fluctuations of the unbalancing, as well as on the types and relative capacities of the pieces of apparatus connected to the three-phase system. In general, polyphase machinery, such as induction motors, synchronous motors and rotary converters, connected to an unbalanced system, will to some extent improve the balance at their own expense, so that such pieces of machinery must have their rating changed or the amount of heating will be greater than the heating would be for the same output on a normal balanced system. How serious this curtailing of rating or increase of heating is, of course, a matter dependent on the particular conditions prevailing on the particular system under consideration. Bearing on this point, Mr. Murray makes one statement that seems open to question: " . . . such (unbalanced voltage) as remains is easily compensated for by arrangement of transformer taps in the substations reducing the three-phase current from high to low voltage for motor or synchronous converter application." While it is a well recognized proposition that any polyphase system can by suitable transformer connections be converted to any other polyphase system, it is not evident that the mere placing of taps on transformers will convert an unbalanced three-phase system into a balanced three-phase system, since any differences in the voltages must be accompanied by changes of phase relation. While suitable transformer taps may be selected so that the voltage from each individual transformer can be given a desired value, these three voltages cannot be interconnected to form a typical three-phase system, on account of the distorted phase relation. It is of course possible to obtain both the desired voltage correction and desired phase relation by the general principles of phase transformation, that is, connecting in series two or more windings having different phase relations. Such interconnection of phases naturally involves specially constructed transformers and some complication of wiring to obtain the desired result, which cannot be accomplished by transformer taps alone.

R. E. Hellman (by letter): There are a few statements in Mr. Alexanderson's paper which, while perfectly correct, might be misleading to the casual reader of the paper. Mr. Alexanderson states " The output of the converter must be substantially one-half of the polyphase capacity of the motor." He also says " The single phase capacity of the converter corresponds to the input of one phase of the motor, or one-half of the total output."

The following statement, which is also correct, might give to some readers, a better idea about the size of the converter— " The polyphase capacity of the converter is exactly the same as the polyphase capacity of the motor." In other words, if the two machines would have the same speeds, they would have to be exactly the same size.

In comparing the phase converter with the motor-generator set, Mr. Alexanderson seems to favor the phase converter somewhat. The generator of a motor-generator set is a polyphase machine and its size would, therefore, be the same as that of the phase converter. The driving motor being single phase would be about 40 per cent larger. Even considering that a motor generator set requires an exciter and that the converter is a squirrel cage machine, I believe that while a comparative weight of 1 to 4.5 may be obtained under special condition, a ratio of 1 tô 3 or 1 to 3.5 would be more correct in the average case.

Mr. Alexanderson's statement that the converter will add only 26½ to 30 per cent to the weight of the motor, of course, is correct under certain assumptions. This question depends, however, entirely upon the possible relative speeds of the motor and the converter. The saving accomplished by the fact that the converter is not a driving machine, is probably not very large in most industrial applications. It is my experience, that the electromagnetic stresses during the starting period of induction machines is usually the governing feature and will not permit a light mechanical structure, except in case of a very large air gap, which in turn, would spoil the power factor. Nevertheless, the system has certain advantages and its application will be well worth considering in some cases. While no mention of the possibility of using the system for railway work, has been made in the paper, this question might be of interest. Since the converter adds 25 to 50 per cent to the motor weight, the total equipment will be as heavy or heavier than the straight single phase commutator motor equipment.

The possible omission of the transformer on the locomotive, which is one of the main advantages of the straight three-phase operation, will, in most cases, not be possible with the proposed phase converter because the equivalent single-phase line voltage would have to be considerably larger. In fact, it is liable to pass the voltage limit for which the converter and the motors could be safely and economically insulated. A transformer on the locomotive will, therefore, be required in the majority of applications.

The application of the system for general railway work seems, therefore, not very advisable, since the introduction of an intermediate revolving machine would reduce the reliability and since the constant speed feature of the induction motor is a disadvantage in general railway work in this country.

In such cases, however, in which three-phase operation is desirable for some reason or other, the proposed system might be considered. Especially in cases where the distances are large, while the number of locomotives is small, some saving in first cost over the straight three-phase system, might be accomplished.

While the rolling equipment will be, of course, considerably heavier as well as more expensive than the straight three-phase equipment, the saving made by the cheaper overhead construction, may possibly more than offset this disadvantage in some cases.

In connection with railway work, I would like to bring up the question of regeneration and ask whether this point has been investigated to any extent. It might also be well to ask the question as to what would happen if the power should be off for a short interval of time, which would permit the phase converter to reduce its speed to any extent. It seems that in such a case, there is danger of the phase converter falling out of speed, especially if it is designed for as high an efficiency as Mr. Alexanderson proposes.

While it is quite possible to obtain a good efficiency with a phase converter, it seems rather difficult to obtain at the same time, good starting conditions for the same, as well as a strong tendency to pull back into speed whenever the power goes off.

In regard to the power factor, it might be said that the total power factor probably would be rather low in spite of the fact that the power factor of the converter may be as high as 95. If we assume for instance a motor with a power factor of 90 and a phase converter with a power factor of 95, we obtain a combined power factor of only 77.5. The same combination at half load would have a power factor of 45 to 50. This is about the most favorable condition which may be obtained. In many cases, especially in case of the lower speed of a two speed motor, the power factor may come as low as 60 or even lower at full load.

In fact the power factor conditions for the phase converter system are very much the same as for two induction motors operating in cascade connection in so far as two machines have to be magnetized. A comparatively low power factor will, therefore, be inherent to the system. Special means for correcting the power factor would further complicate the system, so as to make their use hardly worth while considering in connection with railway work.

E. F. Alexanderson (by letter): In answer to the questions brought up by Mr. Hellman regarding the system of single-phase operation with phase converters and polyphase motors, it can be stated in general that the system is applicable for regenerative breaking in the same way as the three phase system, and that it has been demonstrated that the phase converter has no tendency for falling out of step if the power is interrupted. As soon as the power circuit is broken all the magnetic fields disappear and the phase converter continues to run light, being retarded only by friction and windage. It therefore would take a considerable time for it to slow down to any great extent. However, it was demonstrated that the speed might drop to $\frac{1}{3}$ of full speed, and yet the phase converter would come up to full speed as soon as the circuit was re-established.

The figures given in the paper regarding the relative weight of motors and phase converters are of course in no way to be considered as general—they refer to a specific case of locomotive equipment, which appears to be particularly suited for heavy mountain railway work. Any comparison between the phase converter system and the single phase commutator motors must therefore be considered from this point of view. It can be stated in the case that has been studied that the phase converter system gives a much lower weight of locomotive than the single phase commutator motor. The controlling feature is not so much the relative weight of the auxiliary apparatus as the space factor of the motor itself, which determines the type of locomotive which may be used.

Regarding power characteristics the indications are that the average power factor will be as good as or better than the corresponding single phase commutator motor.

Edwin B. Katte (by letter): The contribution to the discussion of Mr. Murray's paper which I have to offer is based upon some direct current experience, and in order to avoid the impression that I favor direct current to the exclusion of all other systems for trunk line electrification, I will preface my remarks by saying that I believe any steam railroad can be equipped for reliable electric operation with either of the three commonly discussed systems; but that one of these systems will more satisfactorily meet the special conditions of each case, and that at the present time no one system of electrification has been developed to satisfactorily meet all the conditions of every trunk line problem.

It is not a question of direct-current, single-phase or three-phase alternating-current that we should be discussing, but rather steam *versus* electric operation, and until we do confine ourselves to the real issue and can show economy in electric operation, we cannot expect to interest steam railroad men as a whole.

Electrification has proved itself entirely reliable on many steam railroads and in some cases has demonstrated a saving in operating expense. However, I do not know of a single instance in which it has been shown that this saving is sufficient to cover the additional fixed charges, and I hazard the opinion that no trunk line electrification will prove economical as compared with steam until an entire steam locomotive division has been electrically equipped.

Electricity, at the present time, must be considered as more or less of a luxury or as a means to some end other than economy of operation. The great trunk line terminals in New York City would not have been possible were it not for electricity, and the operation of the Detroit River and the Sarnia tunnels would scarcely be safe were it not for electric locomotives; in such cases as these the high cost of electricity is justified. But on the other hand, if a city or other property, through which a steam railroad passes, is to be improved by the elimination of the nuisance of steam locomotives, the cost of this property improvement should be shared in by the city, state or individual in a manner similar to the present practice in the matter of grade crossing eliminations.

With much interest have I read Mr. Murray's statement, to the effect that " we have made electrification in its various forms work, we can now make it pay," and although I have carefully perused every page of his paper, I have failed to find the last statement justified, except in his claim that—"to make electrification pay, he (the electrical man) must be able to reproduce the four classes of steam tractive efforts by electricity, with a total investment, the interest on which must be carried by the economy to be effected over steam operation." Then follow data about water consumed per ton-mile of steam trains and watt-hours per ton-mile for electric trains, concerning which you are all more or less familiar, but not a word regarding the relative cost per ton-mile of steam and electric trains in similar service. It is this cost data in which we are so vitally interested, and this I had hoped to find in Mr. Murray's analysis. Here I may add that cost figures for comparative performance on the New York Central system are not available for the reason that the service is still mixed steam and electric; steam locomotives operate over electrified tracks and multiple-unit trains are hauled a large portion of their run by steam locomotives due to the still uncompleted condition of the Electric Division.

In Fig. 38 Mr. Murray has reproduced several speed-time curves for single-phase locomotive runs and has computed the current consumption in watt-hours per ton-mile for local and express service on the New Haven Railroad. A comparison of current economy based upon watt-hours per ton-mile for different systems on different railroads is not very conclusive because of the effect of grades, curves, station stops, schedule speed, etc., but as an indication of what might be expected in comparing direct-current and single-phase locomotives in the same service, I have selected locomotive runs on the New York Central direct-current system as nearly the same as those given by Mr. Murray as the train schedule will permit, and the results are tabulated below:

LOCAL TRAIN SERVICE

Items	Single-phase loco.		Direct current loco.	
Direction of run	W. bound	E. bound	N. bound	S. bound
Average grade	+0.053%	-0.053%	+0.129%	—0.129%
Train number	213	216	333	1016
Date	2/11/11	2/11/11	6/6/11	5/31/11
Run between	Stamford-Woodlawn		G. C. Term.-No. W. Plains.	
Train weight, tons	316	285	266	250
Length of run, miles	20.6	20.6	23.9	23.9
Time of run, min	55.8	55.8	61.8	62.8
Schedule speed miles per hr	22.1	22.1	23.2	22.8
Number of stops	13	14	20	18
Stops per mile	0.63	0.68	0.84	0.75
Watt-hr. per ton-mile	85.4	74.2	81.6	59.4

EXPRESS TRAIN SERVICE

Items	Single-phase loco.		Direct current loco.	
Direction of run	W. bound	E. bound	N. bound	S. bound
Average grade	+0.053%	-0.053%	+0.129%	—0.129%
Train number	9	16	1005	1004
Date	2/11/11	2/11/11	5/9/11	5/29/11
Run between	Stamford-Woodlawn		M. Haven Jct.-White Pls.	
Train weight, tons	477	493	432	434
Length of run, miles	20.6	20.6	17.11	17.11
Time of run, min	27.6	25.2	23.3	23.4
Schedule speed, miles per hr	44.7	49.0	44.1	43.9
Number of stops	0	0	0	0
Watt hr. per ton-mile	35.0	30.0	29.2	17.6

From the tables it will be noted that the trains selected for comparison are quite similar in weight, schedule speed, number of stops, etc., for each class of service, however there is some difference in the grade of the two railroads, the New Haven having an average descending grade of 0.053 of one per cent from Woodlawn to Stamford, and the New York Central an average ascending grade of 0.129 of one per cent from Grand Central Terminal to North White Plains. For this reason the comparison is made of trains operating in both directions and in all cases, both for express and local trains up or down the grades, the saving in current consumption is in favor of the direct current locomotive.

COMPARISON—ELECTRIC OPERATION
NEW HAVEN R.R. AND NEW YORK CENTRAL R.R. CO.
TRAIN MINUTE DELAYS PER MONTH

	New Haven R.R. Co.				New York Central R.R. Co.				
Month	Power houses	Trans. lines	Elec. loco.	Total	Power houses	Line S. S. 3d R.	Elec. loco.	Total	Loco. miles
1908									
July.......	0	2100	1183	3283	0	10	30	40	86922
Aug.......	132	1642	407	2181	0	33	45	78	89670
Sept.......	0	942	224	1166	0	0	18	18	89324
Oct........	0	2140	343	2483	0	42	30	72	89561
Nov.......	139	103	405	647	0	0	7	7	83822
Dec........	179	194	240	613	0	0	35	35	89738
Total......	450	7121	2802	10373	0	85	165	250	529037
Average per month...	75	1187	467	1729	0	14	28	42	88173
1909									
July.......	0	170	153	323	0	10	45	55	95482
Aug.......	0	548	97	645	0	54	154	208	91160
Sept.......	0	0	219	219	0	7	86	93	93688
Oct........	54	204	124	382	0	0	6	6	94893
Nov.......	0	42	95	137	0	18	27	45	89504
Dec........	0	55	315	370	0	8	12	20	91082
Total......	54	1019	1003	2076	0	97	330	427	555809
Average per month...	9	170	167	346	0	17	55	71	92635

SUMMARY

Total Train Minute Delays for Six Months.

New Haven R.R. Co....................................1908—10373 1909—2076
New York Central Co.................................. " — 250 " — 427

N. Y. C. increase was due to an epidemic of defective fuses on locomotives. Of the 427 minutes delay, 234 were due to defective fuses.

There is no data given by Mr. Murray for converting the watt-hours per ton-mile into dollars and cents to cover all fixed and operating expenses for the entire electric service, and therefore the relative cost of steam and electric operation cannot be determined, and while there may be a saving in operating expense it is not known whether or not it is sufficient to cover the additional fixed charges incurred by the electrical installation.

The statistical record of single-phase operation gives ample proof of the improved conditions of that system; the reduction in train minute delays for the last six months in 1908, namely from 10373 to 2076, in the same months of the following year, is considerable. On the New York Central Electric Division, the train minute delays due to electric trouble for the same period in 1908 was 250 minutes and in the following year 427 minutes, of which 234 minutes delay were caused by an epidemic of defective ribbon fuses which were responsible for more than one-half of the delays before they could all be removed from the electric locomotives.

Mr. Murray points with justifiable pride to the single-phase locomotive performance of 15,700 miles per one locomotive failure. A similar good record has been made by the direct current locomotives, as shown in the New York Central record for March, 1911, of 26,655 miles per one engine failure; the total electric locomotive miles for that month was 106.622.

Again Mr. Murray refers to the single-phase electric locomotive record for reliability, and states that in November, 1909, there were 66,000 locomotive miles performed with but three minutes delay and informs us that upon such ground his Board of Directors stood in ratifying the single-phase system. A better monthly record has been made by the direct current locomotives on the New York Central system, the exact mileage being 101,765 made in April last, the single train detention being of four minutes duration, caused by a broken draw bar knuckle which contained a hidden flaw in the casting. Last month, that is May, 1911, the locomotives performed an average mileage of 112,893 per one train detention of five minutes caused by a defective air brake hose.

Little is said in the paper of the power station for supplying a single-phase system and nothing about its cost of operation; the storage battery is dismissed as a thing of the past, yet both have a very direct bearing on the cost of generating current, which after all is the main source of economy—or expense—in any electric traction system. It is well known that to generate current on unbalanced phases is more costly than on an equally loaded three-phase system; and aside from the insurance feature of batteries, their economical effect in equalizing the load on power stations has frequently been demonstrated. This has again been evidenced in the low cost of generating current at the Port Morris power station of the New York Central Company, where for some time the average cost to generate current has been about one-half cent per kilowatt-hour with coal costing approximately $3.00 per ton. It would be an interesting comparison if Mr. Murray would tell you what it is costing to generate current at the Cos Cob power station for the single-phase system.

It is encouraging to note that the many electrical and mechanical changes in the original New Haven locomotives, which Mr. Murray described in his former paper, have resulted in more reliable operation; this, however, should not be the only index of satisfactory results. The successful electric locomotive should not only be reliable but its maintenance in such condition must be at a low cost. The inspection, repairs, renewals and other maintenance of the New York Central electric locomotives during the first four years of operation have averaged between three and three and a half cents per locomotive-mile for all classes of service. It would be interesting if Mr. Murray would publish similar maintenance costs for the New Haven locomotives.

There is much in the paper concerning the additional weight of the New Haven Company's single-phase direct current equipment. This feature has been criticized before now by some engineers who have wondered—in the light of the knowledge that direct current would have to be used by the New Haven Company for a considerable portion of its mileage—why such a complicated and heavy equipment was ever adopted. No figures were then available to prove that it was more economical or reliable than the lighter and less complicated direct current apparatus, and none have yet been produced.

The figures given for the first cost of the single-phase trunk line electrification system are so very general in character and the range between the high and low estimates so great that no comparison can be made with the cost of the direct current system. However, the impression derived from the unit costs given is that the direct current system would be considerably less expensive, and this impression is in a way substantiated by a comparison of the estimates submitted last Fall to the Joint Metropolitan Committee in Boston by the New Haven Company for single-phase and by the New York Central Company for direct current electrification, wherein the average cost for single-phase electrification was $71,000 and for direct current $59,000 per mile, including all items entering into the first cost of the change of motive power.

Mr. Murray's final remarks are not to my mind conclusive; he states that his paper is not an argument for the single-phase system, that statistical records of first cost and operating expense make such a course unnecessary. No such records of first cost or of operating expense have ever, to my knowledge, been given to the engineering public, and such meager results as are recorded in his paper pertain to but 85 single-track miles of main line now in single-phase operation on the New Haven Railroad between Woodlawn and Stamford, while on the other hand, more reliable operation is to be found over the 126 miles of main line on the New York Central Railroad Company's direct-current system.

My purpose is not to argue the adoption of the direct-current system as opposed to the single-phase system, but to point out as forcibly as I may that the direct-current system has thus far made a better record than the single-phase, and therefore at least two systems of electrification are available for successful trunk line operation, and to urge electrical engineers to strive to prove the advantages and economy of electricity over steam as a motive power and leave the selection of the system to be determined by the requirements of each specific case.

H. Graftio (by letter): Although the New York, New Haven & Hartford Roads present electrification was proved to be a complete success, I cannot agree with Mr. Murray's conclusion and doctrine of the universal use of the single-phase system on trunk lines.

In my opinion one cannot possibly avoid the question of relative costs and merits of electrification by various systems (in hand and to come) for various specific conditions of the lines themselves and of the traffic to be handled on them, and one cannot substitute these very complex questions by the motto: " As electrification of trunk lines is now practically at hand, what is the correct system for all?"

" No system yet at hand is the correct system for all " would be in my opinion the only possible answer to the question, unless one be satisfied with very poor average.

And as regards the recommendation of the single-phase system, among others in hand, (which also proved to be very successful in the respective cases where they are used) to be the universal system, it would really mean too heavy a sacrifice for the two numerous cases of trunk line electrification, where *we really can expect* now to see electric traction advantageously substituting the existing steam traction.

I am by no means adverse to the single-phase system, or an advocate of some other system, but I do consider that one cannot forget the results obtained, for instance, in the recent Pennsylvania electrification with the direct-current system, or the really wonderful performance of the three-phase system used on the Italian lines and among them on the Genova Busalla trunk line.

It seems to me that the whole confusion in the so much talked of question of one single universal system of electric traction for trunk lines is the outcome of one fundamental deviation in pure logics. One very often refers the idea of electrification to entire systems of trunk railroads. So far and while one is reasoning in this general and abstract way, one might be perfectly justified in advocating some single universal system, and it is possible that the single-phase system might be, so far as we stand now, the best suited for such a general purpose, or might not be.

We have had the occasion to hear this same reasoning expressed by some of the reporters at the International Railway Congress held at Bern in July 1910, and so far as the hypothetical case was considered, these reporters were perhaps in some way justified. But the same reporters on the basis of very complete studies of electrification done for Bavaria, for Austria and for

Switzerland, informed us that the electric traction is in such a state as to advantageously substitute the steam traction on trunk lines in two cases, *viz.*:

1. If the cost of energy be less than so many pfennigs or hellers per kw-hr.
2. If the density of traffic has surpassed such and such limits.

Considering the cases mentioned, we see that even for Bavaria and for Austria (and for Switzerland too), whose representatives were precisely the reporters mentioned, practically only two categories of trunk lines *can stand* electrification versus the existing steam traction at all, and those are: mountain divisions of trunk roads sometimes connected with a few short flat divisions adjacent to these mountain divisions and with cheap sources of energy in the vicinity, or suburban sections of trunk roads adjoining large cities with a sufficiently dense traffic on them.

And precisely for these special cases of real practical possibilities of electrification, other systems, such as the three-phase and the direct current come out as more economical and more suitable for purely technical reasons than the single-phase system. This has and can be easily demonstrated by figures for each of these two special cases.

What remains then of the electrification of entire systems of trunk railroads, advocated as the chief argument for the selection of one unique system of electric traction? Nothing. And what is the weight then of considering a unique and universal system of electric traction? Nil; unless speaking of phantoms and dreams, because we cannot underestimate the present Queen of our trunk railroads—the modern steam locomotive, which is and will remain for a long time to come the cheapest and the best suited for innumerable kilometres of our existing railroads, and because we also cannot overlook results obtained by other systems of electric traction.

On the other hand we are progressing so rapidly in the art that nobody can pledge for ten years in advance that some other system will not come forward in the meantime, which would make competition for any of the existing systems hard.

Extrapolation has been always condemned by mathematicians, and in the case of electrification of entire trunk systems, or even lines, where millions are to be spent and where the directors of a railroad company, or the respective governments may ask for some specific explanation as to the return each year of a percentage on some of the money spent, it seems that engineers must be even more careful in this respect than mathematicians.

Let me remark also that, with the exception of motor car trains suited for local traffic, in the long distance service where heavy trains will have to be hauled by powerful electric locomotives, it really will not take more time or give more trouble to replace, at the respective junction station, a single-phase locomotive by a three-phase one, for instance, or *vice versa*, than is being taken now in changing one steam locomotive by another.

The very small complications in the distribution system, that may come out of this (or may not), are not worth mentioning now and cannot seriously be taken into consideration as a reason to overlook much more serious circumstances, such as economy and technical suitability.

The conclusions arrived at the Bern Congress on the question of "systems" of electric traction seem to confirm in the fullest way the above said.

Clause No. 2, of the conclusions of the Bern Congress, accepted by the immense majority of the railroad men and electricians of all countries, both of Europe and of America, that were present and participated in the discussions, says: "There are various systems at hand and the selection of one or another system is dependent on its respective suitability in each case."

So better let now each system develop and fight for its own, as before, in finding more and more of the convenient field for its respective development. The fittest will win.

Gisbert Kapp (by letter): Mr. Murray has done good service to the cause of electrical engineering generally in showing that electrical working of main lines is perfectly reliable. Apart from the satisfaction which every engineer will feel at the success recorded in the paper there are two broad conclusions to be drawn from it. One is the importance of treating electrification not piecemeal, but as one organic and comprehensive change and the other is the importance of standardization. The electrifications carried out hitherto in Europe were mostly tentative and piecemeal work. Under these circumstances the fixed charges on powerhouse and lines and the low load factor of the powerhouse must seriously hamper the economic advantages which can be obtained if the working is extended to all classes of traffic including yard work. Mr. Murray's paper brings out the economical advantage of treating electrification as a matter of general and not partial application. This is also the experience in Europe where not only passenger, but also good traffic is worked electrically, though the extension of electric working to yards has not been carried out so fully as on Mr. Murray's lines. The tendency is however that way also here.

The other broad conclusion, namely the desirability of standardization, is also fully recognized in Europe, but when we come to details we get onto debateable ground. Five years ago the Swiss Government called together a committee to study this question, but although reports were issued there is at present no such thing as standard practice in European railway electrification. Of the three postulates in Mr. Murray's religion namely type of current, pressure and frequency, only the first may be considered as a standard with us. It is true that the Italian Government has adopted three-phase current for some portions of main lines, but there were special reasons for this decision and the Italian Government engineers have by no means closed the door on the single-phase system. Mr. Verola, the chief engineer to the Railway Department stated in a letter to me that it is highly probable that other lines will be electrified single-phase. All the new main lines electrified or to be electrified on the Continent are on the single-phase system and the two examples of main line working we have in England are also running very satisfactorily on this system. We may therefore take it that Mr. Murray's suggestion as to type of current will be readily adopted, but if we come to the questions of pressure and frequency we find the most bewildering variety in present practice. In England and Prussia most lines are worked at 25 cycles, while Italy and the Duchy of Baden have adopted 15 cycles as a standard. The Swiss committee have also recommended this frequency as a standard. One of the reasons why Switzerland has adopted a 15 cycle standard with a 10 per cent latitude up and down is that the existing hydroelectric works have generally frequencies between 40 and 50 and by installing a frequency transformer of 3 to 1 ratio they could utilize their spare power for railway supply. As both Switzerland and Italy are water power countries and as the capital outlay for hydroelectric works is much heavier than for steam driven stations it is a matter of great economic importance to utilize the existing plants to the fullest possible extent and for this reason it seems unlikely that the standard of 15 will be abandoned for one of 25.

As regards pressure we have in Europe also a great variety, including all voltages from 2,000 up to 20,000, but the tendency of new lines is to adopt a pressure in the neighborhood of 10,000 volts. This is not so very different from Mr. Murray's suggestion that one need abandon the idea of coming to an understanding. Mr. Murray has shown that a pressure of 11,000 volts can be safely employed and there is nothing to prevent this standard to be adopted also in Europe.

As regards the design of motors the question whether the frequency shall be 15 or 25 is not of paramount importance. Mr. Eichberg (whose motors are made by the Allgemeine) favors 25, while other firms notably Siemens-Schuckert favor 15, but there is no scientific reason which should make it impossible to design any type of motor for either frequency. As Mr. Murray has shown by his practical success that the frequency of 25 is possible there does not seem to be any very pressing reason to abandon it. The argument that some types of motor can be built a little more conveniently for the lower frequency can hardly be considered to weigh very heavily in comparison with the practical success which has been achieved with the higher frequency.

Discussion at Toronto

N. W. Storer: As Mr. Murray has kindly omitted all reference in his remarks to the locomotive I will make a few remarks about it.

You may think that the greatest point of difficulty in connection with the electrical locomotive today is with the electrical features of it, that is, the design of motors and control, but it may be questioned whether that is absolutely true. There is no question about it that the electrical features have required most careful designing. But I believe the one point that is attracting as much attention from our locomotive designers at the present time as any other, is the method of connecting the motors to the drive wheels. Now, what is the best connection for transmitting the power? We have in the New York Central locomotive probably the simplest. There the field of the motor is made a part of the frame of the locomotive. The armature is pressed on the axle. That has some difficulties in the way of additional dead weight on the axle, which some people claim has been very detrimental to the road bed. At any rate when we discussed with our good friend Mr. McHenry the design of new locomotives, there was one specification which he absolutely insisted on, there must be no dead weight on the axles excepting the axles themselves and the wheels; the motors must be spring supported. That specification has been maintained, and I must say I am in absolute accord with his views on the matter, that there should not be unnecessary dead weight on the axles.

The design of the original locomotive was also limited by the insistence on having no gears. That I believe was a very good thing. I think we have made a greater success of the proposition than we should have done at that time with gears. The motors have been mounted on quills. As probably most of you are familiar with the design I will not attempt to explain it in detail, but the motor is concentric with the axle and drives the wheels through springs. Now, the later forms of locomotives have a gear reduction. This 071 as it is familiarly known has the motors arranged directly above the axle and they are geared down to the quills; the springs connecting the quills with the wheels are long and quite flexible, so that there is sufficient play there to permit the motor to be mounted rigidly on the frame of the locomotive and to move with it, allowing an inch and a half of play either above or below the normal position. That is the easiest riding locomotive I was ever on and I believe I have ridden on practically all of the different types of electric locomotives in the world at this time. Without any question it is the easiest; that is, as far as the comfort of a man in the cab is concerned, and I believe ease on the road-bed as well.

Another type of drive which is now being used to some extent in this country and a great deal abroad is the side rod type. That is a reversion of the old steam locomotive practice. We found that some railroad people were never going to be satisfied until they had side rods on their locomotives. Without them the thing didn't look like a locomotive. Mr. Murray even criticized our first design of locomotive because he said it didn't have any distinctive appearance about it, it didn't look like a locomotive.

Now, this side rod type has been applied on the Pennsylvania electrification at the New York terminal and it is doing very good work indeed. Those locomotives are probably more powerful than any other in the world. They will pull an 800-ton train up a two per cent grade at 30 to 40 miles an hour; they will start the train equally well. That means a good deal when you consider there are only about 100 tons on the drivers and it requires 60 to 70 thousand pounds draw bar pull to do that.

We have been extremely fortunate and I want to say the whole railway world owes Mr. E. H. McHenry the Vice-President of the New York, New Haven and Hartford, a debt of gratitude. He has been perfectly free to accept the responsibility and to afford all of the contractors the greatest latitude in working out designs, to afford them the opportunity to try new devices and new designs which appeared to have merit. At this time there are orders placed and locomotives practically completed of several different designs, or rather modifications, of one or two designs, they are more samples. They have that 071 type which was built as a sample but was found so good that they built the Hoosac Tunnel locomotives identical with it, mechanically and electrically, except that they are straight alternating current instead of alternating current-direct current. They have now a side rod locomotive. 070 has two very large motors driving through side rods similar to the Pennsylvania locomotives. There is in the shop a switcher locomotive which is illustrated in the paper which has the four motors above the axles geared down to quills.

There is the 072 similar to the 071, but with some modifications as found desirable and possible after the experience of building one.

Then there is another locomotive which I feel is going to be one of the best that we have yet been able to produce and that will be known as 069. It is going to be an " earlier " type but it is not quite finished yet. It looks at first thought as if it might be a mistake, as if somebody's slide rule had slipped a little bit, but I don't think that is the case. We have eight motors on that locomotive instead of two which the side rod locomotive takes. We have two motors for each driving axle. The motors are mounted in pairs and geared directly to the quills. We use two motors to replace the one large one. The reason for that is plain, when you consider the matter. The space between the wheels on a locomotive is very limited and when you come to build large motors you find that a very large portion of that space must be used in gears. For instance the large motors on that 071 have two gears of 4¾-in. face each, so that there are 9½ in. gear space; add to that the space required for gear cases and you find you haven't very much space left for the motor. That means that the motor must be made very large in diameter in order to get the torque, which runs up the peripheral speed of the armature and cuts down the output in that way. The smaller motors have been well and thoroughly developed for car uses and they do not require as large a gear. By mounting two of these motors together we can connect them both to one large gear of very much narrower face than the sum of the two gears on the large motor, so that we are able to utilize this space much more efficiently between the wheels than would be possible with a large motor, and we find there is a very material reduction in the weight made possible by that arrangement.

That is, however, not the only new feature about this locomotive. The running gear is quite different. It has four pairs of drivers. There are two middle drivers which are mounted in the rigid frame that the cab is mounted on; instead of having two six wheel trucks as this 071 has there are four drive wheels in the middle of the locomotive, and at each end there is one driving axle and a pony which are mounted in a truck by themselves and swing more like a Mallet locomotive. It has something like a Mallet hinge in there; it is a modification of that idea, but it results in a very light flexible locomotive which I think is going to be a winner. The control instead of being complicated by the number of motors is very much simplified and reduced in weight as well, so everything tends to make that an extremely light locomotive, one that you are going to hear from shortly.

You would be surprised at the interest that is being taken all over Europe and this continent as well on the subject of electrification. In South America they are working on it; they have a number of large propositions and are quite wide awake in Chili, Peru, Brazil and in the Argentine. They are doing wonderful things down there. In Europe they are very much alive to the subject, and with the exception of the Italian State railways all counties have adopted single phase as the medium for the electrification of railways. So that we are not alone in this country in advocating that system. It is the standard which has been selected after great thought and study by the Germans, the Swiss, the French and the Swedes and it has been introduced in England. I received a paper a couple of weeks ago which follows exactly the same line with Mr. Murray's. It is written by Phillip Dawson. He is a prominent engineer in London who has superintended the electrification of the branch of the London, Brighton & South Coast Railway there. That is a line at present only about nine miles in length. Almost within the limits of the City of London. They adopted for that the single phase system, in spite of the most tremendous opposition among engineers there which has been practically of the same nature as in this country. They adopted it and after several years, for things move very slowly in the old country, they put it in service about a year and a half ago, and I had the great pleasure of going over the line with Mr. Dawson last spring, and he explained to me how well they were operating, and I could see from the results they were getting that everything was running in splendid shape. The work was not pushed as fast as it was on the New Haven road and they had the advantage of the experience of other roads which had been operated before they started out, so that I don't think they have had as many interruptions and as much grief as we had on the New Haven road. But, they are getting splendid results and Mr. Dawson's paper is a strong endorsement of the system. The result is just the same as it is in New Haven. They are going to extend it; they are going to extend it right away, and they have voted the money for that purpose. It is a very noteworthy point, that single phase railways are as a rule extending their lines, but it is not very often the case with the direct current lines; when it comes to the electrification of steam railways they hold on a long time before they extend them beyond the limitations which are required by law. The B. & O. Railway electrified its tunnel at Baltimore ten or fifteen years ago and it has the same length of electrification today as it did then. It is a success as far as it goes. The New York Central electrified at the same time that the New Haven did, or somewhat before, but we don't hear any talk of their extending their electrification, but the New Haven electrified with the single phase system is pushing right ahead. They have a system which is flexible and it will admit of the greatest degree of extension. The London, Brighton & South Coast in England is the same way; they can expand and extend their lines.

I have been making a few calculations lately about the loss in power. On a direct current system or any system, with 1,500 volts on the line, with a line say 20 miles long, with two Number 0000 wires for overhead conductors, with a station at each end of that 20 mile line, you run a single car over that line at schedule speed of about 40 miles an hour and you will lose five per cent of your energy in the line. That is with a line only 20 miles long with a sub-station at each end and about 1,500 volts on the line, and only one car. If you run two cars in one train it will double your percentage of loss. Take a single phase system with 11,000 volts on the line, a 40 mile line feeding from one end only, and your average loss in that line with a car going over it will probably not be more than one half what it would be with the single car on the 20 mile stretch.

Single phase equipment is unquestionably heavy; it is heavier than the direct current or three-phase equipment. For that reason it requires more power to carry the car over the line, but when you consider the loss in the line between the car and the substation you will find it is on the other side of the ledger before you get past the substation. There is more power required for the low voltage system. You have got to have high voltage in order to make electrification a financial success.

B. G. Lamme: Mr. Storer has already discussed the locomotive very fully and therefore I will confine my remarks to certain general features of the system, which Mr. Murray has mentioned, but has not emphasized as fully as might be.

Take, for instance, the original system proposed for the New Haven Railway. It was planned to use high voltage directly from the generator, 11,000 volts at 25 cycles feeding directly into the overhead line. One terminal of the generator was to be permanently grounded. This meant that the supply system contemplated an 11,000 volt generating plant with one terminal permanently grounded, connected without transformers to a trolley system comprising over 100 miles of 11,000 volt overhead line. This was a new and untested condition. A further feature contemplated in this system was that it had to be capable of almost unlimited expansion without undue loss or excessive complication.

The locomotive was also a new type of apparatus, but designed along the lines laid out originally for the single-phase system, in which single-phase commutator motors with voltage control were to be used. By this control the speed of the locomotive was to be varied over any range from zero to maximum speed, simply by varying the voltage supplied to the motors by means of a step-down transformer on the locomotive itself. At the same time the locomotive was designed to operate on 600 volts direct current as well as on 11,000 volts, 25 cycles alternating current.

This New Haven system was installed along the above lines and has been carried through to an entirely successful operating condition and, while certain minor changes have been made, it will be almost impossible for an electrical layman, as you might call him, to find these changes. I mean by this, that if he had looked over the system rather completely in the first place and would look over the present system and equipment, it would be difficult for him to see any differences or changes which would appeal to him as being of any controlling importance. However, a number of changes from the original installation have been made, and I wish to call attention to the fact that these changes have consisted almost entirely of *additions* to the system and equipment to meet unknown or new conditions which have developed since the system was first installed, that is, these changes have not been made to correct what might be called mistakes or errors in the original layout. Also, a number of the modifications may have been in the nature of developments which will find application in other fields besides single-phase railway work. Take, for example, the generating plant. In order to adapt very large capacity generators for single-phase railway operation, new problems were encountered which had not proven serious in small size machines. For instance, complete cage dampers were put on the rotors of the generators to repress the pulsations due to the single-phase armature reaction. Since these machines were installed it has become a recognized practice in all very large high-speed single-phase generators to equip the rotors with some sort of cage dampers. Such generators are coming into use for other purposes besides railway work, electrochemical work and electrofusion being examples.

Take another feature of the generating plant, namely, the addition of choke coils in the leads between the generator and the overhead system, as was described in connection with Mr. Murray's former paper before the American Institute in December 1909. These choke coils were added for the purpose of reducing the enormous current rushes which occurred in the case of short circuit on the line. This practice of using choke coils for the protection of large turbo-generators is now being applied in a number of cases in connection with three-phase high voltage machines. The application of this principle which is used in the New Haven single-phase plant is now being carried into other fields than single-phase railway work.

Take another feature, namely, the selective system which is developed in connection with the New Haven overhead system. In this system, in case of a short circuit, a resistance was introduced to take up the load before opening the circuit. The object was to avoid suddenly opening an enormous inductive load, with consequent possible disturbances on the generators and system. In order to open the circuit the inductive load was first transformed to an energy load by means of the introduction of resistance, and then this energy load, of considerably reduced amount, was opened by the breakers. This arrangement contains the germ of a practice which may eventually be carried into the whole field of transmission work.

Considering the transmission line, the use of the steel trolley wire below the main wire may be regarded as an addition pure and simple, and a very helpful addition from a mechanical standpoint. The original copper trolley wire served two purposes, namely, as a feeder or conductor, and as a contact wire for supplying current to the locomotive. The addition of the steel wire takes away from the copper wire its function of a contact wire, but it still serves its function as a conductor. The copper wire could not be taken out and the steel put in place of it, as the low resistance of the copper conductor is needed. Therefore, the copper still serves its more important function and the steel wire placed beneath it takes care of the mechanical requirements.

In the locomotives a few changes have been made since the original installation but they have been of a comparatively minor nature. The principal changes have been in the nature of additions rather than modifications. For example, part of the control system was increased in carrying capacity on account of the fact that the motor capacity actually proved greater, by about 15 per cent, than originally expected. The change in the control to take advantage of this increased capacity cannot be charged to a mistake or error, but should be credited as an improvement to obtain increased capacity. The original guaranteed continuous capacity of the locomotive motors was about 830 amperes. Some of these motors, on actual test, showed a continuous rating of approximately 1,000 amperes. This increase in capacity over what was proposed can now be taken advantage of in the operation of the system.

In connection with the original overhead system there was considerable talk about the possible large line drop. In practice, that question has not troubled anyone. A more serious trouble has been that the line drop has been very small, so that in case of short circuit anywhere on the line, enormous current rushes would occur which were destruction to the system. These were later taken care of by the choke coils and the selective system, as mentioned before. This low line drop, however, is just what is required if extensions are to be made in this system. Mr. Murray now announces that the present overhead system is to be continued down into the Harlem Yards, and his figures indicate that even with the enormous extension which is contemplated the maximum line drop will still be comparatively small.

Taking this system as a whole, it may be noted that the original voltage of 11,000 has been maintained; also, the original frequency of 25 cycles. No transformers had been added and the system can be extended as originally intended. The fact that the 100 miles of overhead work is now being increased to 500 miles without transformers shows the flexibility of the system. In all the history of electrical engineering I do not know of any undertaking which had as many new and untried features as this system has, which has been carried through to success with as close adherence to the original lines.

There is one feature in connection with the generating plant which has not had its full significance brought out before. I refer to the use of 11,000 volt machines with one terminal grounded. These generators have three-phase armature windings of the star type with one of the three terminals permanently grounded. Two of the legs of the star are used for the single-phase circuit, while the third leg is used in connection with certain three-phase work. Across the railway phase the potential is regulated for 11,000 volts normal, by means of an automatic regulator in connection with the fields of the generator. The third leg gives a little higher voltage normally, due to the small load which it carries at present. In consequence, its voltage is usually somewhere between 11,000 and 12,000 volts. Assuming this at 11,000 volts, then in these machines we have an equivalent, as far as insulation stresses go, of a three-phase generator with grounded neutral *with* 11,000 *volts between the neutral and the terminals*. This therefore is practically the equivalent of *a* 19,000 *volt three-phase generator with the neutral grounded*. It is more than this, as it is the equivalent of a 19,000 volt machine with the neutral grounded and *with the terminals tied directly to* 100 *miles of* 11,000 *volt overhead system without the interposition of transformers*. This is a very abnormal condition compared with anything that is being done in this country at present. 16,500 volts is the highest generator now used on a large scale, as far as I know. But here we are actually running under conditions corresponding to

19,000 volts with the hardest kind of service and with an overhead line without transformers which is going to be extended to about 500 miles. Under these conditions the generating plant has made an extremely good record, as indicated by Mr. Murray in his table of delays due to power house. I may say that for about two years, or possibly more, there has been practically no trouble as far as the generators are concerned; that is, any trouble which would shut down the system. There has been one breakdown in one machine, but a careful examination of this one case developed no cause for the breakdown other than a damage to the insulation in originally putting the coil on the machine. There were no signs of deterioration of the insulation, and the insulating materials on the damaged coil appeared to be as sound and flexible as when first put on. So here we are running machines at the equivalent of 19,000 volts on a three-phase system, and during two years there has been continuous service. This is a most excellent record. If we compare this with a late practice, now being advocated here and there, of winding large turbo generators for low voltage, such as 2,200 volts, and then stepping up to voltages, even as low as 6,600 volts, we can see what a wonderful thing this New Haven operation is. In some cases at the present time, 11,000 volts, or even 6,600 volts on the generator, is being condemned as bad practice because of dangers from line voltage, surges, lightning and such things, but in this New Haven plant there are 100 miles of overhead system under conditions where it is exposed to surges of the worst sort.

Referring again to the locomotives, the motors were popularly considered as the questionable feature of the whole system. Of the first type of locomotive, 41 were built, all of the gearless type with four motors each. The motors furnished, which were 250 to 300 h.p. were by far the largest up to that time. These motors were supplied with the so-called resistance leads which were considered by many to be a very harmful feature and a source of great loss. These locomotives have been in operation between three and four years and as far as we have had an opportunity to examine the resistance leads on the armatures of these locomotives they have shown no signs of over-heating or undue loss. In fact, in one case which I examined personally the copper winding showed more evidence of heating than the resistance leads. It should be borne in mind also that at times these motors have been very heavily overloaded. The record as a whole may be considered as good as that of corresponding direct current motors.

One very good feature has developed in these single-phase locomotive motors, namely, they are able to commutate well over an extremely wide range of speed. In the ordinary direct current motor of the non-interpole type, the commutating conditions become perceptibly worse as the motor speed is increased when carrying a large current. On the single-phase motor this condition is not encountered to the same extent. The short circuit current in the resistance leads decreases as the speed is increased so that the reduction in such current with higher speed compensates, to a considerable extent, for the effect of the increase in speed, so that the commutation as a whole seems to be equally good from very low speed up to very high speeds. This is of particular advantage in a system where voltage control is used, for it allows us to push up the voltage applied to the motors whenever there is occasion to do so.

Mr. Murray mentioned a new locomotive of the side-rod type, with two large motors. These motors are of nominally 600 h.p. continuous rating at about 200 revolutions at normal voltage. Claims have been made from time to time that with 25 cycles it was not possible nor practicable to build single-phase motors of more than 200 or 300 h.p. continuous rating, but tests on these 600 h.p-motors indicate that they work just as well as motors of 100 h.p., for instance. These motors have been loaded up to 100 per cent overload current and they commutate just as well as smaller ones.

In conclusion, I will say that the single-phase system in this country has its greatest example in the New Haven electrification. There are also a number of smaller systems which use single-phase railway motors, such as the Spokane & Inland Railway in the far West, and the Sarnia Tunnel near Detroit, which uses single-phase electric locomotives entirely. In Europe they have not put the single-phase system into commercial use on as large scale as in America, but in a number of European countries the single-phase system already has been adopted as standard for heavy railway work, and they are expecting to install the system on a comparatively heavy scale in the near future. Although the experience in Europe with this system is as yet more limited than in this country, yet it has satisfied them that the system can be adopted for main railway electrification.

W. S. Murray: With the exception of Messrs. Sprague and Katte, those who have contributed to the discussion—both on the American and European side—seem to be in general agreement with the author, but for a few exceptions with reference to details of the system. The author is left, after reading the discussion, with the impression that single-phase power is correctly used when applied to trunk line roads inclusive of terminal, suburban and yard rails. The opening paragraph of the paper advocates this application, and it is most gratifying to find the general support of this recommendation.

Mr. Sprague implies that I said that the time has come when the electrical engineer can say that there is but one system of electrification to meet all the varied problems of railroading. Nowhere in the paper is such a statement made, nor one that could be interpreted to involve such a conclusion. It should be remembered that street railways and trunk lines are two entirely different propositions. In answer to the criticism that no mention of costs is made in the paper I call attention to that part of my paper devoted to electrification costs and under this is discussed power house, line and locomotive costs, and with the closing remarks that " not until the electrical system of the New Haven Road is a unit in itself, rather than a mixed service of steam and electricity, can its true economies of electrical traction be discussed ". An extension to New Haven will give this, though even then the highest economies of the single-phase system cannot be realized, due to the necessity of a large portion of locomotives and multiple unit equipment being required to do dual service on alternating-current and direct-current lines. As the electrification only covers 1/5 of the zone ultimately to be included it is not expected that information as to operating costs would be of great value. It does not advance the application of electricity to railroads to proclaim the disappointment at not receiving data which is practically unavailable to the railroad company itself.

Mr. Sprague summarizes the railway system advocated in the paper by the following characteristics:

1. " Single phase transmission at a potential limited by the requirements of the trolley wire from central stations equipped with generators built with variable voltages and operated with grounded circuits ".

2. The abolition of the step-up and step-down transformers.

3. A potential of 11,000 volts or higher on a trolley line in contiguous territories, but with entire freedom to change that voltage to something different on remote lines.

4. The abolition of the single-phase 25 cycle motor and the substitution therefore, as a possibility in the near or the dim future, of a single phase induction motor, or in lieu of that the much criticized direct-current motor supplied by a mercury rectifier or its equivalent.

Commenting on these characteristics it should be noted in connection with (1) that variable voltage generators were not included. The New Haven road has used and intends to use only constant potential generators unless later conditions require otherwise. With reference to (2), the system described does not rule out the step-up or step-down transformer. We are contemplating using some shortly but the distances of our transmissions to date are short enough to be economical without them.

With reference to (3) Mr. Sprague states the situation correctly.

With reference to (4). It is common knowledge that the cost of power stations of the single-phase or three-phase type may be equated. It is common knowledge that single phase propulsion equipment is more costly than direct-current equipment; *but it is also common knowledge among those who have had practical experience with the accounts incident to alternating-current and direct-current operation that it is in the distribution system that the economy of single-phase traction lies.*

Having admitted that direct-current propulsion equipment is less costly than alternating-current, and notwithstanding this fact that the *single-phase system* is more economical than the *direct-current system*, why, if 25 cycles is the frequency more conducive toward a reduction in propulsion apparatus cost for the reasons mentioned in the paper, should it not be advocated?

Thus I believe that the discussion has wandered from the particular points and system described in my original paper.

Mr. Katte criticises the absence from my paper of figures for relative costs per ton mile of steam and electric trains in similar services. Yet in the same paragraph of his discussion says " Here I may add that cost figures for comparative performances on the N. Y. C. system are not available for the reason that the service is still mixed steam and electric ", thus ignoring the fact that the same difficulty exists on the New Haven. There is in addition the complication due to the operation with both single-phase and direct current.

In connection with the subject of train delays which is brought out in Mr. Katte's tables due consideration should be given to the relative ages of the two systems employed. It is not remiss to mention here that of all the roads entering New York City, the New Haven had last year the record of handling the highest percentage of trains on time.

Mr. Katte claims a higher efficiency for the New York Central locomotives than for the New Haven. He states that trains of similar weight are handled by the New York Central at an average energy consumption of 23 watt-hr. per ton mile whereas he gives figures for the alternating-current run between Woodlawn and Stamford on the New Haven of 32.5 watt-hr. per ton mile. I do not know where the figure for the New Haven services was obtained but I deny that for equal conditions of load and service the New Haven *takes* 42 *per cent more power than the New York Central.*

My own calculations are based on the fact that it is conceded that the alternating-current motor has a range of efficiency 2 per cent below that of the direct-current motor. The published curves of the New Haven and New York Central locomotives show this. Under the condition named the watt-hours per ton mile are a straight function of the locomotive efficiency, which means a difference of 2 per cent as against 42 per cent. Moreover, carrying these calculations back to the power house the fact should be borne in mind that a 15 per cent saving in transmission losses offsets the loss in the motor over six times. The cost of the actual coal burning is proportional to the energy generated at the power station and not to that consumed by the locomotives.

I wish to take this opportunity of thanking Messrs. Fritch, Woodbury, Jackson, Storer, Lieb, Scott, Dawson, Smith, Taylor, Lamme, Graftio, Kapp and Steinmetz for their liberal discussion to the paper. I find myself with the feeling, after reading their contribution to the discussion, that in the specific matter of what type of electrification should be applied to trunk line rails inclusive of terminal, suburban and yard service, that if not entirely individually sustaining, their general conclusion sustains the author's point of view. Some of these gentlemen have differed with the author, and quite decidedly in points of detail, and for this difference of opinion I of course hold only the highest respect and acknowledge the valuable information presented.

Briefly commenting on the discussion of the gentlemen above referred to, it is extremely gratifying to find Mr. Fritch in agreement with my recommendations as to standardization. He epitomizes the situation in saying: " As long as the system is not established you are simply furnishing ammunition for those who do not desire to electrify." Particularly pertinent do I consider Mr. Fritch's remarks with reference to the electrification of yards. By the use of the overhead system the problems of readjustment of obstacle and equipment clearances, the disbarment of certain classes of rolling stock and the general complication and awkwardness incident to a ground conductor are eliminated and the yards and terminals can be treated, in so far as ground conditions are concerned, in a manner exactly as in the past. It is common knowledge that in yards the least amount of money possible is spent on track and ballast—two items in intimate difficult relationship with reference to the adjustment of the ground conductor (third rail) whose location is a matter of the fraction of an inch, while in the case of the overhead wire its unit of adjustment is the foot. The simplicity of the overhead construction and its susceptibility to a standardization for all railroads is easily apparent.

I have read with a great deal of interest and instruction Mr. Woodbridge's discussion with reference to the matter of storage batteries for trunk lines, and I am interested to note that he believes there are places where the battery would be of economic value. It is due Mr. Woodbridge for me to say that I had the specific cases of the New Haven and the New York Central electrifications in mind. In the case of the former it would have been quite uneconomical, and having conferred with the New York Central engineers about the installations of the batteries upon their lines, I was advised that had they to do it over they would not be installed, and in their contemplated extensions no batteries would be installed. It might be well to say here also that both the New Haven and the New York Central roads are of a class typical (in the heavier form) of trunk lines I have had in mind in connection with recommendations made in the paper.

With reference to the closing paragraph of Mr. Smith's discussion, which seems to epitomize what has preceded it, I would say I am heartily in agreement with Mr. Smith that the future may develop some method less costly both as to investment and daily operation than the system now employed by the New Haven road for the electrical operation of their trains. I should indeed be greatly disappointed if what we have today is not greatly improved upon in the future. Let us, however, while hoping for better things, not hesitate to go ahead with the foundations already laid. Because we may believe what we have is the correct underlying principle and advance it in every way in the field of practical application, cannot possibly dim the chances of some better system of the future to take its place.

I feel that the underlying principles of the single-phase system have been sufficiently exposed to ratify its post, and to build on them in the future. In my opinion it will be more costly to wait than to go ahead. It cannot be denied that a universal standard of trunk line electrification would be most acceptable to all railroads. With the exception of a very few engineers, we hear it said that all three systems will work—the direct current, three-phase and single-phase. If this is so, then let us elect one and apply it to trunk lines to be electrified, and I believe we have enough data to date to show that the single-phase for this class of electrification has inherent in it the economic factors necessary to its selection as the standard. It seems to me the time is at hand, or very nearly, when we must select and not enumerate. There is a limit to the capacity of any ship. If she has to carry much more discussion she may sink.

I am very glad to have Dr. Steinmetz' agreement with reference to frequency. The reasons he has presented, together with those mentioned in the paper in connection with the possible future introduction of the induction or direct-current motor, still using the single phase system of distribution, would seem to be entirely consistent.

I think Mr. Taylor has brought out a good point of information, with reference to the difference between phase and voltage balance, and while what he says is quite true, I do not see that it makes necessary any change in the quotation he has cited from the paper.

With reference to Mr. Lamme's and Mr. Storer's discussion, I can only express my thanks for the interesting points brought out with reference to the generator and locomotive features of the system; the developments in these departments being due almost entirely to the patience, pluck and ingenuity of these gentlemen.

With reference to Mr. Graftio's discussion, I cannot see how his " Queen " (the steam locomotive) can be used as a reason against a choice of system for standardization. His " Queen " includes in it all the variable (speed and torque) characteristics that have unified steam standardization, and they can be all duplicated in single-phase locomotives.

Mr. Kapp's conclusion with reference to standardization is most encouraging. It is interesting to note that in Europe there is a strong trend to standardize and it is most gratifying to know that for trunk lines the type of electrification has practically been settled upon in favor of single-phase.

The paper was presented to give up to those who have responsibilities, or to whom later responsibility for electrification of steam road bed may come, information that to the date of the paper had been collecting in my files. Minute costs relating to investment and operation, due to the incomplete state of electric engine stage (division run) was avoided and this feature of electrification was touched upon only in the most general way. The now acknowledged and indisputable principles of economy inherent to the single-phase system as applied to the trunk line system is the guarantor of the results that may be reasonably expected when a sufficient time has passed to stretch its length into an engine stage.

DISCUSSION ON MAGNETIC PROPERTIES OF IRON AT FREQUENCIES UP TO 200,000 CYCLES." NEW YORK, NOVEMBER 13, 1911. (SEE PROCEEDINGS FOR DECEMBER, 1911.)

(Subject to final revision for the Transactions.)

Harold Pender: I should like to call attention to the fact that the results of this paper are confirmed by some experiments which were performed at the Institute of Technology last year under my direction by F. B. Silsbee. The method used was entirely different. For the high frequency generator we used an arc giving a frequency something like 200,000 cycles per second. This frequency was impressed upon a primary winding on a small iron core made up of very fine iron wire, and the electromotive force induced in a secondary winding on the same core was measured. This secondary induced electromotive force was also calculated on the assumption that the true permeability is independent of the frequency. In making this calculation the proper allowance was made for the non-uniform distribution of the flux in the core, usually referred to as the magnetic skin effect. The measured and calculated electromotive forces were found to agree quite closely.

B. A. Behrend: This paper is interesting in bringing again to our attention the question of high frequencies, a question which 20 years ago was perpetually under controversy. The paper of this evening is extremely instructive, although I regret that the able author does not strongly bring out the fact that, as far as fundamental laws and principles are concerned, the problem confronting the physicist or the electrical engineer, whether frequencies of 10 cycles, 25 cycles, 60 cycles, 120 cycles, or 100,000 cycles are involved, remains exactly where it was before; in other words, the permeability of iron as such remains unchanged independent of the frequency. This fact has, I believe, been known for some time. The high frequency induces vitiating factors which make it appear as though the permeability of iron were different for different frequencies, which it is not.

There is another point in the paper on which I wish to comment and that is the point of efficiency of high frequency apparatus. The apparatus may have a high efficiency, as the author has stated, but the apparatus is useless in its present form for practical applications other than wireless telegraphy, because of its want of regulative properties; in other words, a transformer or a generator of high frequency, though its efficiency may be entirely satisfactory, is an inferior piece of apparatus, in fact, an impossible piece of apparatus for the operating conditions required by the use of current consuming devices of low power factor.

The statement which I have made is of a certain measure of importance and of interest to those of us older men, who argued in former years strongly in favor of lower frequencies in order to be able to design satisfactorily transformers, generators, and motors. The higher efficiency of the high frequency transformer may be a great desideratum, yet its lack of regulative properties, owing to the high frequency, makes it an impracticable piece of apparatus for modern power plants.

Charles P. Steinmetz: The importance of this paper appears to me two-fold; first, in announcing the success of developing an alternator capable of generating at 200,000 cycles. It is very difficult, from the mere number, to realize what 200,000 cycles means. We were very proud when we succeeded in generating 10,000 cycles, one-twentieth of that frequency. We must realize that 200,000 cycles is 40 times as high a frequency as the highest frequency at which sound is audible; the pitch at which the ear fails is 1/40 of this frequency. The most powerful research instrument we have, the oscillograph, fails at 1/40 of this frequency, and even at 5,000 cycles it gives merely a single kick without shape or characteristic.

If we would send a current of 200,000 cycles into a line conductor, we would find that while the current flows into the conductor at one point, only 2,000 ft. away the current is still flowing in the opposite direction, is half a wave behind, and is zero 1,000 ft. away, at the center, and when the current stops at one point it is still maximum only 1,000 ft. away.

The second important feature of the paper is the information it gives us of the behavior of iron at these extremely high frequencies which are far beyond any machine frequency ever produced, but which are the frequencies of industrial importance in our wireless telegraph and telephone systems. The paper gives the quantitative values, showing that the permeability of iron at these frequencies is unchanged, and furthermore showing that with commercially practicable thickness of iron, while the eddy currents in the iron are formidable, still the effective permeability is 180 times that of air, that is, iron is still 180 times as good as air as the core for a 200,000 cycle transformer or reactive coil.

This may have an industrial value bearing in wireless apparatus. As you know, in wireless systems we transform the energy produced by the oscillating discharge from the voltage of the generator circuit to the much higher voltage impressed upon the antenna, by a transformer or auto-transformer, which is an air core apparatus. In these cases we deal not with alternating voltages, but with oscillating voltages; trains of waves which gradually, and usually quite rapidly, decrease in amplitude and then die out. The important problem, then, is to get the rate of dying out, the attenuation of the waves, as low as possible, to get as well sustained waves as possible, that is, to reduce the losses in transformation.

Iron has not been used in these transformers, not always because people did not believe iron would follow the frequency, but because the general impression is that the losses in the iron, even when as thin as commercially feasible, would be so formidable as to greatly increase the attenuation, increase the rapidity of dying out of the wireless wave.

As to the question of the magnetic action of the iron, the apparent permeability, I estimated theoretically, some years ago, the frequency at which the apparent permeability of iron, as affected by the eddy currents in the iron, would become inferior to air, that is, at what frequency the permeability would drop down to one, and I found this frequency to be of the magnitude of hundreds of millions of cycles, that is, up to a hundred million cycles iron still increases the magnetic flux, when using the thinnest feasible commercial sheet iron. But long before that, while the iron still increases the magnetic flux, it also increases the loss, and the increased loss, increased attenuation of the wave would make it useless.

Mr. Alexanderson's investigation gives for wireless frequencies, 200,000 cycles, definite numerical results of the apparent permeability, and shows this to be of the magnitude of 180. Thus iron is 180 times as good a conductor of magnetic flux as air, and in such transformers the losses in the iron are of the same magnitude as the $I^2 R$ loss. If we would redesign this iron core transformer tentatively designed by Alexanderson, to eliminate iron, using an air core, then the section of the air core to carry the same magnetic flux would have to be 180 times the size of the iron core used; that is to say, the length of the coil would have to be $\sqrt{180} = 13$ times as great; and to save half the loss, the core loss in the iron, we would have to increase the other half of the loss, the $I^2 R$ loss, 13 times.

So you see this investigation seems to show that by using an iron core of proper proportion, at wireless telegraph frequencies, we can materially improve the efficiency of the transformer or auto transformer, and so reduce the attenuation of the oscillating wave, and that is the problem of the power in wireless telegraphy.

Naturally, this design may be more or less, possibly materially modified, by the problem of the voltage that we have to generate, and the necessity of insulating for the voltage, which must be taken into consideration; but in general it seems from the conclusions of this paper that there should be a material advantage in wireless telegraphy in using iron core transformers, or auto transformers, instead of the air core apparatus used at the present time.

Reginald A. Fessenden (Communicated after adjournment): For long it was supposed that iron lost its permeability at high frequencies, and was not able to respond quickly enough. This theory was a plausible one if Weber's theory that magnetization was due to currents circulating round the atoms, or if Kelvin and Maxwell's dictum that the electromagnetic rotation of light demonstrated conclusively that, to quote Maxwell, " some phenomenon of rotation is going on in a magnetic field ", be accepted.

But about 1890 or earlier J. J. Thomson had shown that iron had a permeability of at least 200 for frequencies of 1,000,000 per second, by measuring the velocity of propagation of an electric wave along an iron wire. In March 1895 the writer showed that the phenomena of magnetism could be explained both qualitatively and quantitatively by the theory that ionic charges, or electrons, circulated round the molecule with the velocity of light and that the maximum ferric induction so calculated agreed very closely with that found experimentally. Also, in March 1900 (*Phys. Rev.*) the writer showed that the mathematical work on which Kelvin and Maxwell based their conclusion was erroneous, in that the fundamental assumptions made virtually implied a theory of matter which was not justified, and that furthermore electromagnetic rotation could be mathematically deduced from the equations for an electric wave passing through an absorbing medium, without any assumptions as regards the nature of matter or of rotation, being a necessary consequence of the lag produced in the wave by the absorption and the presence of electrons.

Theory and J. J. Thomson's results were thus in agreement, but to what extent was unknown. Some experiments made with arc-produced high frequency currents in 1901 showed that the permeability of iron was of the same *order* as for low frequencies, but it might be a fifth as much or five times as much, for arc-produced high frequency currents are very unreliable, even when apparently continuous, having sometimes as much as 50 per cent of the waves missing, and also fluctuating so much in frequency as to make it absolutely impossible to get any accurate quantitative results. (*Lond. Electrician*, Feb. 15, 1907. Later confirmed by Fleming.)

Mr. Alexanderson's results form therefore the first definite and dependable knowledge in regard to this subject, and the paper is remarkable, both for its general interest and its scientific and practical importance. Workers with high frequency currents can now go ahead with confidence and use iron without fear. It will undoubtedly come into use as transformers, especially with the heterodyne system, where the electrostatic inductance between primary and secondary is of no importance and the shortening of the wave length along the wire winding does no harm, but may even in certain cases, be advantageous. I am able to confirm Mr. Alexanderson's statements as to the accuracy of the method used for measuring the power lost.

F. B. Silsbee (communicated after adjournment): In connection with Mr. Alexanderson's paper I would like to give a brief account of an investigation along similar lines which I carried on during the winter of 1910-11, at the Massachusetts Institute of Technology, under the direction of Professor Pender.

The object of the research was to decide whether or not iron can respond magnetically to a very rapidly alternating magnetomotive-force. Especial care was taken to arrange the conditions of the experiment so that they would be amenable to mathematical analysis, and all disturbing factors could be allowed for. The method used was quite different from Mr. Alexanderson's, as the specimens were magnetized by a primary winding, and the flux determined by measuring the voltage in a secondary winding. To allow for the magnetic " skin-effect " a careful mathematical analysis was made which took into account the effects of both eddy-currents and hysteresis. The assumptions it was necessary to make were: first, that the hysteresis loop, traversed by the iron during a complete cycle, was a simple symmetrical loop having the equation

$$\left(\frac{\mu H-B}{\nu B_0}\right)^2+\left(\frac{H}{H_0}\right)^2=1 \qquad (1)$$

where H = m.m.f. per cm. at any point.
B = corresponding flux density.
H_0 = max. value of H during the cycle.
B_0 = value of B corresponding to $H=H_0$.

$$\mu=\frac{B_0}{H_0}$$

$$\nu=\frac{B \text{ at } H=O}{B \text{ at } H=H_0}$$

and second, that μ and ν were constant and independent of H_0. The iron used had been hardened in drawing so that the maximum permeability was only about 700. It was, however, very well suited for this investigation as μ was practically constant at 80 for values of H_0 between O and 3.5 c.g.s. units, ν also was practically constant over this range. From the above assumptions it can be proved that the secondary voltage is of the form

$$E_2=-M_0\,\omega\, I\,[B+\nu A+j\,(A-\nu B)] \qquad (2)$$

where M_0 = mutual inductance between the two windings at low frequency.
ω = 2 π times the frequency.
I = primary current.
j = $\sqrt{-1}$

A and B are functions of the radius of the core, the conductivity, permeability and hysteretic constant of the iron, and of the frequency; and are expressed as a rather complicated series.

The secondary voltage was measured by an alternating current modification of the potentiometer method, so commonly used in direct-current work. A variable inductance and resistance were connected in series with the primary winding, and the secondary winding was connected, in series with a suitable detector, so that its voltage was opposed to the $I\,Z$ drop in the impedance. The inductance and resistance were both adjusted until there was no current in the detector, thus eliminating any demagnetizing action from the secondary coil. Then from the known values of the resistance and inductance, and the primary current, as measured by a hot-wire ammeter, both the magnitude and phase relation of the secondary voltage could be computed.

The high-frequency current was obtained from a Poulsen arc formed between copper and carbon electrodes in an atmosphere of coal gas. The arc was supplied with 220 volts direct current and gave about two amperes at 350,000 cycles per second. The frequency was measured by the use of a resonating circuit, loosely coupled inductively to the primary circuit and containing inductance and capacity in series with a detector. The resonating circuit was adjusted for maximum current, and the frequency computed from its constants by the formula,

$$f = \frac{2\pi}{\sqrt{L C}} \qquad (3)$$

The detector used in this and also in measuring the voltage of the specimen was a thermo-couple heated by the passage of the high-frequency current, and connected to a low resistance D'Arsonval galvanometer.

Four specimens were used, made up of fine iron wire 0.009, 0.005, 0.004, 0.002 in. (0.228, 0.127, 0.101, 0.050 mm.) in diam. respectively. Each size of wire was wound into a ring of circular cross-section about 8 cm. in diameter, and having a total sectional area of iron of about 0.2 sq. cm. Great care was taken in insulating between adjacent wires. The material was passed through thick shellac, and thoroughly dried by a blast of hot air before being wound into the ring. The electrical resistance between the ends of the iron wire after winding was practically that computed from its length and resistivity, thus showing that there could be no short circuit between turns.

It will be seen from equation (2) that when the potentiometer circuit is balanced

$$L = M_0 \, (A - \nu B)$$

$$R = M_0 \, \omega \, (B + \nu A)$$

This was found to be the case in most of the measurements to within 3 or 4 per cent which was the limit of precision of the measurements. This shows that the true permeability μ is unaffected by frequency up to 350,000 cycles, at least over the range of H used. In some cases there were quite wide discrepancies but it is probable that they were due, at least in part, to the rise in temperature as suggested by Mr. Alexanderson. The observed values of the energy component were uniformly low, which suggested that possibly the hysteresis loss per cycle might be less at the higher frequencies, when the molecules are subjected to such rapid agitation. Such a decrease in hysteresis has been suggested by Ewing, Lodge and others. It would be interesting to know if Mr. Alexanderson has separated his core losses, so that this fact could be determined.

A paper to be presented at the 267th meeting of the American Institute of Electrical Engineers, New York, January 12, 1912.

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(Subject to final revision for the Transactions.)

SOME NOTES ON ISOLATED PLANTS

BY PERCIVAL R. MOSES

It is perhaps necessary to offer some excuse for presenting to The American Institute of Electrical Engineers some notes on isolated plant design and operation. The general impression is that designing an isolated plant is hardly to be dignified by the term "engineering". The central station looms so large and the cost of the large central plant so greatly surpasses the largest isolated plant, in the general opinion, as to place questions of design of such stations in a different class from the questions entering into the design of an isolated plant.

Few realize that in reality the design of an isolated plant involves the consideration of as many factors as the design of a central station, and while it is true that there are no isolated plants as large as the plants of the New York public service corporations and similar companies, yet these plants are frequently of many thousand horse power. In the aggregate the isolated plants of a large city far exceed the total horse power of the public utility companies. An engineering directory of the isolated plants in the City of New York lists a total of 1700 isolated plants. The aggregate boiler horse power of the isolated plants, according to this directory, amounted to over 929,000 h.p., and the aggregate engine h.p. to 669,855. The boiler horse power of the largest central station in New York is listed by the Public Service Commission at 109,000, so the listed boiler horse power in private plants containing engines is over eight times the horse power of the largest central station.

If the list given in the engineering directory is substantially correct, we have nearly a million horse power of boilers in operation in the isolated plants in the City of New York (Borough of Manhattan) alone. My estimate is based on the amount and cost of fuel used in about 50 buildings in New York City, and the engineering pay roll in these buildings. I find that the cost of fuel burned in these buildings varies from $10.00 to $22.00 per boiler h.p. installed. The lower cost is for low-grade fuel in a plant operated on a ten-hour basis, and the highest cost for No. 1 buckwheat coal in an apartment hotel plant of large size, operated twenty-four hours a day. The pay roll varies from $9.00 to $16.00 per boiler h.p. installed. A conservative estimate of the fuel and labor used in the isolated plants in the Borough of Manhattan would be $28.50 per boiler h.p., and on the basis of the list in the engineering directory this would indicate a total expenditure for fuel and labor of over $28,000,000 per year, compared with a total of about $5,000,000 paid for fuel and all the salaries and wages of the largest central station company.

In 14 States of the Eastern Middle and Central groups there were 5,923,302 horse power of boilers and 5,544,888 h.p., of engines listed in isolated plants whereas the census reports for the *whole U. S.* gives 3,712,000 h.p., as the total central station engine horse power.

In view of the magnitude of these figures, I believe that I am justified in referring to the isolated plant problem as an " engineering " problem and one worth most careful study and consideration.

PRESENT CONDITIONS OF ISOLATED PLANT DESIGN AND OPERATION

The design of an isolated plant is seldom given the benefit of a sufficient study of the facts. There has not been the wide interchange of data from small isolated plants; operating engineers are usually too busy or too fearful to publish their results. They regard central stations as an enemy ready to shut down their plants, regardless of whether the rate obtained will pay a profit or not. Whether they are justified in this attitude or not is immaterial. The result has been to make it difficult to obtain actual data on the performance of private plants, except in the large mills and similar industrial establishments. Private plants located in buildings adjoining each other use fuel of different grades, one costing perhaps $5 a ton and the other $3. A recent investigation of department stores revealed the fact that some of these stores are burning low-grade fuel costing less than $2 per ton, others are burning No. 2 buckwheat at a cost of $3.25 per ton, and still others are burning pea coal costing $4.10; and one store is burning egg coal, costing in the neighborhood of $6 per ton. It has been equally difficult to get accurate records of loads. Few plants keep regular logs; there are many trustworthy exceptions; and the lack, until recently, of accurate and simple means of measuring the feed water supply to the boiler and the steam delivered, made it practically impossible to obtain continuous records of boiler performance. These conditions were recognized many years ago by the author, and in the plants with which he has had to do, he has endeavored to have regular logs kept, from which reliable data could be obtained on which to base design of subsequent similar plants. A number of load curves from typical buildings derived from such data sheets—log sheets—will be presented a little later, with the hope they may be of use to others designing plants for similar buildings.

Isolated plants vary from a simple plant, consisting of a boiler and an engine, or simpler still, of an oil engine or water wheel, to the complex equipment of a modern hotel, department store, sugar mill or chocolate factory, containing boilers, gas producers, engines, dynamos, switchboard, motors, refrigerating machinery, heating, evaporating and concentrating apparatus, pumps, elevators, ventilating fans, etc. Perhaps the most perfect example of an isolated plant is the modern Trans-Atlantic 1000-foot liner with boiler horse power equaling the horse power of the largest central station, but with the additional complication of moving the ship and its parts.

The isolated plant, properly speaking, is a central plant for the supply of all the heat, light and power requirements of a building, while the usual central station is a central station for the supply of an isolated product.

In discussing isolated plant design it is impossible to confine the investigation to the electric plant alone. It is important to realize fully that the manufacture of electricity is only a small part of the work of the isolated plant. It is one of the processes going on in a building, just the same as refrigeration, heating and the moving of the passengers. The parts are interlinked and interdependent, and with the increase in size and complexity of the modern building and the consolidation of adjoining buildings, this interdependency and interaction becomes more and more

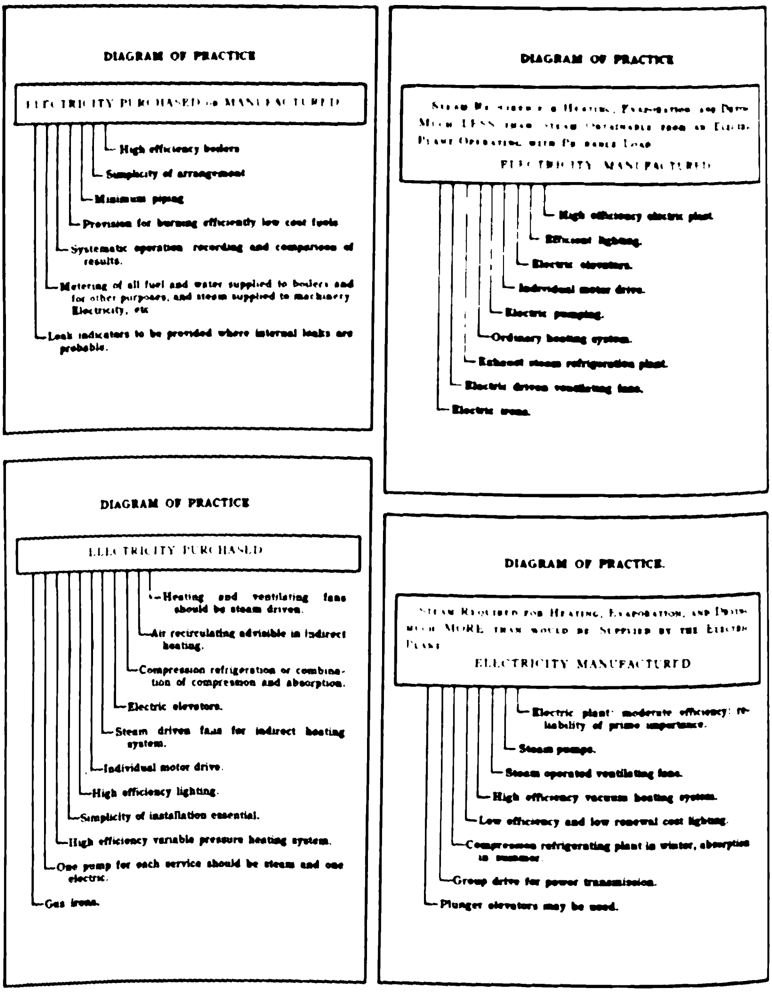


DIAGRAM OF PRACTICE
ELECTRICITY PURCHASED or MANUFACTURED
High efficiency boilers
Simplicity of arrangement
Minimum piping
Provision for burning efficiently low cost fuels
Systematic operation recording and comparison of results.
Metering of all fuel and water supplied to boilers and for other purposes, and steam supplied to machinery Electricity, etc
Leak indicators to be provided where internal leaks are probable.
DIAGRAM OF PRACTICE
Steam Required for Heating, Evaporation, and Drying Much LESS than Steam Obtainable from an Electric Plant Operating with [illegible] Load
ELECTRICITY MANUFACTURED
High efficiency electric plant.
Efficient lighting.
Electric elevators.
Individual motor drive.
Electric pumping.
Ordinary heating system.
Exhaust steam refrigeration plant.
Electric driven ventilating fans.
Electric irons.
DIAGRAM OF PRACTICE
ELECTRICITY PURCHASED
Heating and ventilating fans should be steam driven.
Air recirculating advisable in indirect heating.
Compression refrigeration or combination of compression and absorption.
Electric elevators.
Steam driven fans for indirect heating system.
Individual motor drive.
High efficiency lighting.
Simplicity of installation essential.
High efficiency variable pressure heating system.
One pump for each service should be steam and one electric.
Gas irons.
DIAGRAM OF PRACTICE.
Steam Required for Heating, Evaporation, and Drying much MORE than would be Supplied by the Electric Plant
ELECTRICITY MANUFACTURED
Electric plant: moderate efficiency; reliability of prime importance.
Steam pumps.
Steam operated ventilating fans.
High efficiency vacuum heating system.
Low efficiency and low renewal cost lighting.
Compression refrigerating plant in winter, absorption in summer.
Group drive for power transmission.
Plunger elevators may be used.

Diagrams Showing the Effect of Different Basic Conditions on Isolated Plant Design important. To emphasize this point, a few of the ways in which the design of each part affects the other, may be noted:

The heating design affects the structural engineering, power plant design, character of the electric lighting used, type of pumps, type of ventilating apparatus.

The electric supply affects the power plant design, the heating system design, the electric lighting design, the refrigeration plant, pumping apparatus, manufacturing equipment.

The refrigerating plant affects the design of the water supply, design of the power plant, both as to size and type of apparatus, pumping plant and ventilating equipment.

The type and design of elevator machinery affects the structural design, and the design of engines, dynamos and storage battery. Although these are not strictly germane to the discussion of the isolated plant, it may be noted that the sprinkler equipment and the plumbing lay-out are also affected by all the items above mentioned.

The diagrammatic representations shown herewith indicate the effects of different basic conditions on plant design.

A fair example of the interdependence and interaction of the modern plant is a new building on Fifth Avenue. It is distinctly a typical office and loft building and contains offices on the upper floors, lofts for show, and sales rooms on the middle stories; and the first four floors are occupied by the owners as a retail store for ladies' wear. The building (173 by 90 ft., 52.7 by 27.4 m.) is 11 stories and contains basement and a partial sub-basement for the plant.

The various factors that occur in the design of this isolated plant are the following:

(1) Heat must be supplied to keep the building warm and also to warm the air supplied for ventilation.

(2) Basement, first floor and sub-basement have to be very completely ventilated, and as no radiators are permitted on the first floor, the ventilation and heating for this floor are combined. It is particularly important that the air supplied shall be clean and free from dust.

(3) The building must be equipped with sprinklers, and a complete system of fire protection provided.

(4) Water must be pumped and supplied to all toilet rooms, offices, to a number of other locations, as well as to fire standpipes and sprinkler equipment.

(5) Passengers must be carried to and from the various offices and lofts, and a special service of a different class must be furnished for the stores' customers.

(6) A fur storage room, 50 by 60 ft. (15 by 18 m.) and 13 ft. (4 m.) high, must be kept at from 20 to 26 deg. fahr. by the circulation of dry refrigerated air. Filtered and refrigerated drinking water is to be provided at a number of points on each floor.

(7) Electricity must be supplied for lighting large spaces and for localized illumination. Electricity must also be furnished to a number of fan and sewing-machine motors, pressing irons and cutters, as well as to the large motors operating the pumps and elevators.

(8) Compressed air must be supplied for elevator door operation, and the air must be exhausted for operating cash system carriers and for vacuum cleaning.

(9) The space below general sewer level must be drained and the drainage discharged into the sewers.

The above nine important functions are to be performed in this modern building. How do they affect each other?

A calculation of the losses through walls, windows and exhausted air shows that the heating of the building does not require as much steam as the required electric plant will give. This indicates, if any electric plant is installed, the necessity of using efficient engines for driving the dynamos; also the use of high efficiency mazda lighting when not otherwise objectionable, and the use of electric pumps because of their greater efficiency.

The excess of exhaust steam available also points to the use of a vacuum heating system to keep the back pressure on the electric plant to a minimum.

The effect of the heating design on the ventilating equipment is self evident, but it is perhaps well to note that the excess of exhaust available points to electric drive for the ventilating fans.

The source of electric supply largely determines the character of the heating system. If the supply of electricity is to be obtained from a central station, a back pressure on the steam heating system would not be objectionable, in fact a steam heating pressure variable at will is advisable; electric pumps and electric driven ventilating fans are not advisable during the heating season, but high efficiency lighting becomes even more necessary than before. The refrigerating plant should be steam driven and probably of the compression type in order to give exhaust steam, while if electricity is made on the premises, the exhaust steam available points to an exhaust steam operated absorption refrigerating plant.

Motors will be planned largely for group drive with a plant and for individual drive with purchased electricity.

The refrigeration design has a most important effect on the design of the water supply, as on the size and type of the refrigerating plant will depend the arrangement of water piping, the amount of storage capacity, the method of automatic pump governing and quite possibly the system of water supply risers throughout the building and the decision as to whether it will prove advisable or not to install a well.

The refrigerating design will affect the power plant piping design because of the use in the retort or generator of steam at a higher back pressure than that carried on the main parts of the plant.

The design of the ventilating equipment will be affected even if cooling of the rooms is not directly planned, because the water used on the refrigerating plant will probably be partly used for air cleansing and cooling in the ventilating plant.

This interdependence of parts could be followed out through all the list, but sufficient has been given to show its extent.

EFFECT OF INTERDEPENDENCE ON GENERAL DESIGN

The close reaction of one factor to another, points to two main features frequently neglected in design:

1. Compactness.
2. Simplicity.

If possible, I would place all of the machinery, except the boilers, in one room.

The cross connections between the component parts of the plant make it very advisable that they should be close together, both because of the initial cost and because of the decreased cost of upkeep due to less lengths of pipe, fewer joints, reduced condensation, etc.

As the whole equipment is interacting, it should be under the direct observation of the engineer, and all parts should be clearly in view and not placed off in separate little spaces where leaks and bad performance will not be noticed. Separate pump rooms have been advocated, because pumps always leak.

The unavoidable complexity of the modern heating, lighting, refrigerating, vacuum pumping and elevator equipment makes the utmost simplicity in design necessary.

I do not mean to neglect safeguards but the excessive duplication of piping and valving to prevent some possible mishap, often results in the trouble it is designed to prevent, as the valves and the mains begin to leak through cross expansion strains and neither line can be shut off. Complication of engine valves, cylinders and receivers with a view to decreased steam consumption often wastes more in labor cost than is saved in steam consumption. The possibilities of steam turbine applications to isolated plants, notwithstanding a lower steam efficiency, lie wholly in their simplicity of operation.

Compactness and simplicity are of the greatest importance, and one might add reliability. I do not minimize the importance of steam or electrical efficiency.

In this discussion I am treating more of the design of the whole plant than of any one part. To obtain overall efficiency of operation the problem must be considered as a whole. An efficient and high-grade heating equipment with equally efficient and high-grade electrical refrigerating and elevator plants may be put together and form a most inefficient isolated plant; and *vice versa*, a poorly planned extravagant electrical system may not affect the over-all efficiency perceptibly if the heating and refrigerating plants absorb all the waste energy.

As an example of the first proposition, I will cite an office building in New York in which every part was of the very highest standard—high efficiency elevators, steam appliances in a restaurant of the best type, a corliss valve steam driven refrigerating and ice-making plant, a most complete and efficient electrically driven ventilating system, a most modern water tube high-pressure boiler and a nearly perfect system of electric installation, but the cost of heat, light, ventilation, power and elevator operation was over double the cost in a similar building, with apparatus much less costly and refined.

The reasons were clear: A high pressure steam plant with night and day force was required for the refrigerating plant and kitchen steam, so that the operation of an electric plant would have added little to the labor cost, but electricity was purchased, and as this purchased electricity was used to drive the fans of the ventilation system, two things resulted. The electric bill was increased and the steam for heating the air required for ventilation had to be obtained from the boilers. If the fans had been steam driven and the exhaust from the steam engines been used to heat the air, the electric bill would have been reduced by several thousand dollars and the cost of steam would have been no greater during the heating season when the fans are mainly used.

The water from the refrigerating plant was originally wasted, because the plumber had nothing to do with the refrigerating plant and laid out a perfect system of plumbing, regardless of the other parts.

The elevators were electric and were operated by purchased electricity, and live steam direct from the boilers was used for heating, whereas it might just as well have operated engine and dynamos first and then made power for the elevators.

This installation has since been changed by the addition of a private electric generating plant. The use of electric driven ventilating fans and pumps is now entirely correct, because the electric plant gives sufficient exhaust steam for all the heating. The water from the refrigerating plant is saved as far as possible, and it is the intention to install an air washer, through which the excess condenser water will be recirculated, cooling the air and the water at the same time by evaporation. It is of interest to note,.in passing, that a gross saving of over $1,000 a month has been obtained since the plant installation. This includes the profit from the sale of steam and electricity to an adjoining building. Regarding the converse proposition that a combination of inefficient apparatus may result in efficiency, it is evident that if the demands for low temperature steam (250 deg. or less) exceeds the supply available from the private generating plant, even if the electric system is a 240-volt two-wire lighting plant or some similar electricity waster, this loss efficiency will not affect the over-all economy of the plant materially. Such conditions exist in sugar mills, dye houses, salt blocks, chocolate factories, harness blacking factories and the greater number of those chemical factories that depend upon evaporation for their product. In city buildings, other than factories, this condition also frequently exists during a part of the year, but seldom during the whole period.

FUEL USED FOR HEATING AND OTHER PURPOSES

I would like to give figures of pounds of steam used to heat buildings of different types and sizes, but my facts come in dollars and tons; and it is hoped that the discussion will bring out other data.

I have not attempted to derive any formula from these figures. The facts and conditions are given, and while each case will differ from those given, the figures presented should allow an intelligent engineer or owner to estimate closely the probable cost of supplying steam to a building of one of the types given. I use the figures myself and find my estimates prove closely correct.

COST OF FUEL AND LABOR FOR HEATING IN TYPICAL BUILDINGS WITHOUT PRIVATE ELECTRIC PLANTS

Apartment Houses

No. 1.—100 by 100 ft. (30 by 30 m.) 7 stories and basement—21 apartments—one elevator.
Steam for heating and hot water and pump. Fuel used No. 1 buckwheat at $3.25 per ton........................ Fuel $1150 to $1250
Labor $1200 to $1320

No. 2.—200 by 100 ft. (61 by 30 m.) irregular—8 stories and basement—72 apartments—two elevators.
Steam for heating and hot water, laundry dryers and pumping. Fuel used costs $2.05 per ton.. Fuel $2350
Labor $2276

No. 3.—200 by 92 ft. (61 by 28 m.)—11 stories and basement—block front—77 apartments—elevators.
Steam for heating and hot water. Coal for heating. Coal for hot water amounted to 300 tons in a year. Stoves for dryers. Fuel used, pea coal.. Fuel $4317
Labor $2800

No. 4.—(Corner)—100 by 100 ft. (30 by 30 m.)—12 stories.
Steam for heating, hot water dryers, refrigerating plant and pump. Used 1050 tons No. 1 buckwheat.............................. Fuel $3700
Labor $2465

I have no figures from hotels without private electric plants larger than 50 by 100 ft. (15 by 30 m.) 12 stories. Almost all such hotels in New York have their own plants. Those that have not do not give out their figures.

Hotels

No. 5.—Apartment hotel. 50 by 100 ft. (15 by 30 m.) 10 stories...... Fuel $2700
Labor $1920

No. 6.—High class apartment hotel. 50 by 100 ft. (15 by 30 m.) and annex 25 by 100 ft. (7.6 by 30 m.).—4 stories.
Heating hot water and refrigeration. Absorption system. Low pressure steam.. Fuel $2503
Labor $1920

Office Buildings

No. 7.—100 by 100 ft. (30 by 30 m.)—12 stories—corner building.
Corner heating and some hot water.............................. Fuel $1700
Labor $2500

No. 8.—Corner—offices—11 stories—86 by 150 ft. (26 by 30 m.).
Heating, steam for kitchen and refrigerating plant. Steam for hot water (25 h.p. and up).. Fuel $3564.65
Labor $3746.25

No. 9.—50 and 30 by 197 ft. (15 and 9 by 60 m.).
12 stories—protected on west.................................. Fuel $1047.50
Labor $2020.00

$3067.50

No. 10.—Offices.
Steam for heating. Plunger elevators. Pumping and hot water.... Fuel $4383.35
Labor $5798.52

$10,181.87

No. 11.—Offices 45 by 85 ft. (13.7 by 25.9 m.)—16 stories—corner—three electric elevators.
Fuel $1,180
Labor $ 810

$1,990

No. 12.—Loft building—50 by 100 ft. (15 by 30 m.)—12 stories, middle of block protected.
Fuel $800
Labor $420

No. 13.—100 by 100 ft. (30 by 30 m.)—Salesrooms—12 stories. (Corner).
Fuel $1,580.00
Labor $5,798.00

No. 14.—128 by 90 ft. (39 by 27 m.) and 173 by 90 ft. (52.7 by 27 m.)—Mail order house—11 stories and basement.
Steam for heating hot water. 4 plunger elevator pumps and house pumps..........Fuel $4,621
Labor $4,100

No. 15.—75 by 185 ft. (22'8 by 56.3 m.)—12 stories and basement—middle of block but exposed above lower floors..........Fuel $1,280
Labor $713

No. 15 (a).—16 stories—123 by 143 ft. (37.4 by 43.5 m.) (Corner).....Fuel $2700
Labor $ 960

Department Stores

No. 16.—207 by 100 ft. (63 by 30 m.) and 25 by 104 ft. (7.6 by 31.7 m.) and 90 by 75 ft. (27 by 22.8 m.).
Steam for heating refrigerating and pumps and hot water. Hydraulic elevators. 7000 kw-hr..........Fuel $6,583
Labor $6,084

No. 17.—92 by 122 ft. (28 by 39 m.) and 253 by 184 ft. (77 by 56 m.)—7 and 10 stories. yard (anthracite) screenings and soft coal..........Fuel $5,967
Labor, $5,000

No. 18.—23,000 sq. ft. (2,137 sq. m.)—seven stories—six passenger and three freight elevators (plunger type) No. 1 buckwheat anthracite..........Fuel $4,000
Labor $5,000

No. 19.—200 by 200 ft. (61 by 61 m.)—6 story and basement.
Use No. 2 buckwheat coal..........Fuel $5,231
Labor $4,056

No. 20.—Factory and loft building—two buildings about 12,000 sq. ft. (1,579 sq. m.) per floor—6 stories and basement..........Fuel $1,100
Labor $936

Labor Costs. The figures given opposite labor for each building are within 10 per cent of the actual pay roll.

Some owners engage cheap engineers and firemen and take a chance—others, more careful of their own property and their tenants' lives, have good engineers.

Several disastrous fires could not possibly have gotten the headway they did, nor could such loss of life have occurred, if an intelligent and highly organized power plant engineering force had been on the premises.

Electric Loads. The electric load curves showing the variation in use of electricity in a number of differing buildings, offer a fair basis for estimating probable requirements under similar conditions.

There is a general tendency to overestimate the maximum electric demand due in great measure to the possibility of all the lights being in use at one time or of all the elevators starting at once.

Practically speaking such conditions are not possible, and experience enables us to determine in advance within 10 per cent or 15 per cent what the maximum load will be for a stated size and type of building.

It is for this purpose that the load curves are particularly useful. Such load curves also aid in determining the probable kilowatt hour use per month or per year, but I find the most convenient method is to compare buildings of similar size and character. For this reason I give data on the quantities used in buildings of various types and sizes.

KILOWATT-HOUR CONSUMPTION OF ELECTRICITY IN BUILDINGS

Lofts and Manufacturing Buildings

No. 21.—185 by 200 ft. (56 by 61 m.)—12 stories, basement and sub-basement, 464,084 kw-hr. All kinds of light manufacturing; 12 elevators; electric heating for manufacturing.

No. 22.—100 by 100 ft. (30 by 30 m.)—12 stories and basement, 180,910 kw-hr. Corner. Four elevators. Printers on top three floors. Holiday goods manufactured on four floors.

No. 23.—100 by 100 ft. (30 by 30 m.)—12 stories and basement; ventilating plant, 212,483 kw-hr. Four elevators. Cloak and suit manufacturing. Middle of block.

No. 24.—100 by 100 ft. (30 by 30 m.). 12 stories. Corner. Textile Salesrooms; 180,000 kw-hr.

No. 25.—75 by 185 ft. (22.8 by 56.3 m.). 12 stories and basement; 140,000 kw-hr. Four elevators. Silk salesrooms and cloak manufacturing.

No. 26.—44 by 100 ft. (13.4 by 30 m.). 12 stories and basement; 100,000 kw-hr. Two elevators. Cloak and suit and other manufacturing.

No. 26 (a)—123 by 143 ft. (37. 4 by 43.5m.) 16 stories—corner. No manufacturing. 240,000 kw-hr.

Office Buildings

No. 27.—50 by 140 ft. (15 by 42.6 m.). 12 stories and basement; 143,320 kw-hr. Four electric worm gear elevators.

No. 28.—85 by 150 ft. (26 by 45.7 m.). 11 stories and two basements. Restaurant on first floor. Stores and sales lofts on three floors. Five elevators. 260,000 kw-hr.

No. 29.—100 by 100 ft. (30 by 30 m.) 12 stories; 1 basement corner; 4 elevators; no restaurant. Radiator and vacuum cleaner store on first floor. 187,000 kw-hr.

No. 30.—55 by 100 ft. (16.7 by 30 m.) 12 stories and newspaper offices; five high speed electric elevators. 600,000 kw-hr.

Hotels

No. 31.—100 by 100 ft. (30 by 30 m.) 12 stories and 2 basements; three electric worm gear elevators; one sidewalk lift; laundry machinery; transient trade. 325,000 kw-hr. (from ammeter record).

No. 32.—50 by 200 ft. (15 by 60 m.) 12 stories and basement; no laundry; four electric worm-gear elevators. (ammeter record.) 240,000 kw-hr.

No. 33.—50 by 100 ft. (15 by 30 m.) 12 stories and basement; small laundry; two electric elevators; absorption ice machine; 100,000 kw-hr. (watthour meters).

Apartment Houses

No. 34.—Five houses covering block 500 by 100 ft. (152 by 30 m.); 6 stories and basement; tenants pay for electricity; five electric elevators; small stores under one building; moderate priced apartments. 125,000 kw-hr.

No. 35.—200 by 100 ft. (60 by 30 m.) irregular; 8 stories and basement; two elevators; steam pumps; 72 medium priced apartments. 85,000 kw-hr.

No. 36.—200 by 92 ft. (60 by 28 m.) 11 stories and basement; four elevators; electric pumps; 77 apartments; tenants pay for electricity. 100,000 kw-hr.(approx.)

No. 37.—100 by 100 ft. (30 by 30 m.) 12 stories; corner; 3 elevators; tenants light included in rent (48 apartments), 114,000.

No. 38.—200 by 100 ft. (60 by 30 m.) 12 stories and two basements, with annex 50 by 100 ft. (15 by 30 m.) 8 stories and garage; tenants pay for electricity; electric pumps half year; lavish public lighting. 193,000 kw-hr.

DEPARTMENT STORES

No. 39.—230 by 100 ft. (70 by 30 m.) (irregular); 7 stories and two basements; plunger elevators; arc lighting for selling part; mazda for other portions; steam driven cash blower fans and pumps and elevators. 600,000 kw-hr.

No. 40.—92 by 122 ft. (28 by 37 m.) and 184 by 253 ft; 7 stories and 10 stories; Tungsten lighting; electric elevators; absorption ice machine and steam pump. (Lighting inadequate) 900,000 kw-hr.

No. 41.—200 by 300 ft. (60 by 91 m.) 8 stories; one and one-half basements; plunger elevators; approximately lighting excellent; service of highest grade cash blowers; electric driven conveyers; electric driven ventilating plant. Approximate kw-hr. 2,300,000.

LOAD CURVES

The curves presented herewith are taken from hourly readings, noted on regular log sheets, of which sample forms are reproduced from an office building, an apartment house and an industrial plant.

The readings are, in all cases, the nearest to the steady load readable; that is, the engineer waits until the cessation of the jump caused by an elevator or several elevators starting before noting the current. Probably the readings usually include some of the running current, because while there are many periods even in a busy building when the elevators are not drawing current these intervals are infrequent and hard to catch.

Discussion of Load Curves. Load curves 1 and 2 show the variation in electric load in two apartment hotels. No. 1 is a hotel catering mainly to high class permanent residents, built on a plot 50 by 200 ft. (15 by 61 m.)—12 stories and basement—containing four electric elevators, 10-ton refrigerating and ice-making plant, the usual kitchen steam-using appliances, but no laundry. The hotel has 300 guest rooms and 200 baths, hence the demand for hot water is an important factor. All the water used is pumped to a tank above the roof.

There are about 1000 outlets for lights and the total connected capacity is about 100 kw., excluding elevator motors.

The elevator load which is extremely variable is equalized by a storage battery. The hotel has had its own plant for over seven years, abandoning central station supply. The maximum load occurs from six to eight o'clock p.m. and is about 100 kw. This includes about 20 kw. charging current. The ratio of maximum load to connected capacity is therefore 80 per cent.

This ratio is very high because the number of outlets installed is restricted to the minimum requirement consistent with sufficient light.

Curve 2 shows the conditions in another hotel, a large imposing structure covering a block front in New York City which

DAILY LOG SHEET OF INDUSTRIAL PLANT Wednesday, January 11, 1911.

	Gen. No. 1		Gen. No. 2		Gen. No. 3		Gen. No. 4		Gen. No. 5		Exciter No. 2		Rotary No. 2				Steam plant				
																	Temperature		Steam pressure		
Time	Volts	Amps	Volts	Amps	Volts	Amps	Volts	Amps	Volts	Amps	Volts	Amps	A.C. Amps	Amps Field	D.C. Volts	D.C. Amps	F. W.	Cond. W.	High	Rec	Vac.
6 a.m.	6200	15		15		16	125	1600		1600	110	58	6.6	7.3	125	440			142	33	
7 "	6200	16		16		17	125	1750		1750	110	58	6.6	7.3	125	460			144	35	
8 "	6000	17		17		17	125	1500		1500	110	58	6.1	7.3	125	420			145	36	
9 "	6000	17		17		17	125	1600		1600	110	58	6.5	7.1	125	440			145	36	
10 "	6000	16		17		17	125	1600		1600	110	58	6.5	7.2	125	440			145	36	
11 "	6000	17		17		17	125	1500		1500	110	58	6.2	7.3	125	420			144	35	
12 m.	6200	16		17		17	125	1500		1500	110	58	6.2	7.3	125	440			142	33	
1 p.m.	6000	16		17		17	125	1700		1700	110	58	6.5	7.3	125	440			140	30	
2 "	6000	19		19		19	125	1700		1700	110	58	6.5	7.3	125	460			140	30	
3 "	6000	18		18		18	125	1600		1600	110	58	6.3	7.2	125	440			142	33	
4 "	6000	18		18		19	125	1650		1650	110	58	6.0	7.2	125	420			143	34	
5 "	6000	18		18		19	125	1500		1500	110	58	6.4	7.4	125	430			143	34	
6 "	6300	13		13		14	125	1650		1650	110	60	6.4	7.8	125	440			145	36	
7 "	6400	13		13		13	125	1700		1700	110	60	6.6	7.8	125	460			145	36	
8 "	6400	12		12		13	125	1700		1700	110	60	6.6	7.8	125	440			144	35	
9 "	6300	14		14		14	125	1800		1800	110	60	6.6	8.0	125	460			142	33	
10 "	6400	12		13		13	125	1900		1900	110	60	6.8	8.0	125	460			140	30	
11 "	6400	12		12		13	125	2050		2050	110	60	6.6	8.0	125	440			140	30	
12 "	6300	14		14		15	125	2000		2000	110	60	6.4	7.8	125	430			143	34	
1 a.m.	6400	12		13		13	125	1950		1950	110	60	7.0	8.0	125	480			143	34	
2 "	6300	12		13		13	125	1900		1900	110	60	7.0	8.0	125	480			145	36	
3 "	6300	12		13		13	125	1950		1950	110	60	7.0	8.0	125	480			145	36	
4 "	6300	12		13		13	125	1900		1900	110	60	7.0	8.0	125	480			145	36	
5 "	6300	12		13		13	125	2000		2000	110	60	6.6	7.8	125	440			145	36	

Chief Electrical Engineer

DAILY LOG SHEET OF OFFICE BUILDING

Date April 3. 1911.

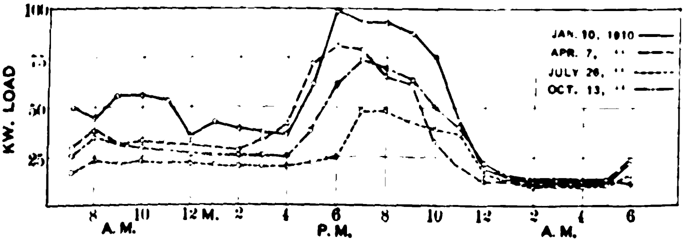
	Amperes							Volts		Steam		Temperatures					Pressures		
	Generators					Battery				Boiler press.	Back press.	F. W.	H. W.	Brine		Room	Ammonia		Brine
Time	1	2	3	Total	Neut.	Charge	Disch.	Plant	Batt.					In	Out		Head	Back	
7 a.m.	110	110		220		50		240	220	110	4			5	6	92	115	5	25
8 "	125	125		250		50		240	280	110	5			6	5	94	115	5	25
9 "	200	200		400		50		240	260	110	5			6	5	94	115	5	25
10 "	230	230		460		50		240	260	110	5			8	7	94	115	5	25
11 "	245	245		490		50		240	260	110	5			9	8	96	115	5	25
12 "	155	155	155	465		50		240	260	110	5			9	8	96	105	5	25
1 p.m.	155	155	155	465		50		240	260	110	5			9	8	96	105	5	25
2 "	165	165	165	495		50		240	260	100	5			11	10	98	105	5	25
3 "	165	165	165	495		50		240	260	110	5			12	11	98	105	5	25
4 "	175	175	175	525		50		240	260	110	5			15	14	100	105	5	25
5 "	170	170	170	510		50		240	260	110	5			15	14	100	105	5	25
6 "	155	155	155	465		50		240	260	110	5			13	12	100	105	5	25
7 "		125	125	250		50		240	290	110	4			12	11	100	105	5	25
8 "			125	125				210		105	3			11	10	100	105	5	25
9 "			100	100				240		105	3			11	10	100	105	5	25
10 "			75	75				240		105	3			12	11	100	115	5	25
11 "			60	60				240		100	3			14	13	98	115	5	25
12 "			50	50				240		100	3			14	13	98	115	5	25
1 a.m.							30		250	100	3			12	11	98	115	5	25
2 "							25		240	105	3			10	14	98	115	5	25
3 "							25		240	100	3			9	8	98	115	5	25
4 "							35		240	100	3			7	6	96	115	5	25
5 "		45		45				240		105	3			7	6	96	115	5	25
6 "		75		75		50		240	270	105	3			5	4	96	115	5	25

	Water meters				Watt meters			
	A. M. and Co.		Maillard					
	No. 1	No. 2	Croton	Tank		No. 1	No. 2	No. 3
Pres. read.....	4,244,930	91,670	509,490	316,240	Pres. read.	2890	2129	9026
Prev. read.....	4,240,750	91,450	506,390	315,780	Prev. read..........	2,846	2,015	8,942
Difference......	4,180	220	3,100	460	Difference..........	54	114	84
					Constant...........			
					Kw. hours..........			
Average temperature—Fair.					Total kw-hr........			
Condition of bearings—A.M.					Boilers in use......	X	X	
Condition of bearings—P.M.								

SUMMARY.—Fuel, 18,900 lb.; Ashes, 24 cans; Eng. Oil, 2 qts.; Cyl. oil, 4 qts.; Lamps, 33.

Chief Engineer.

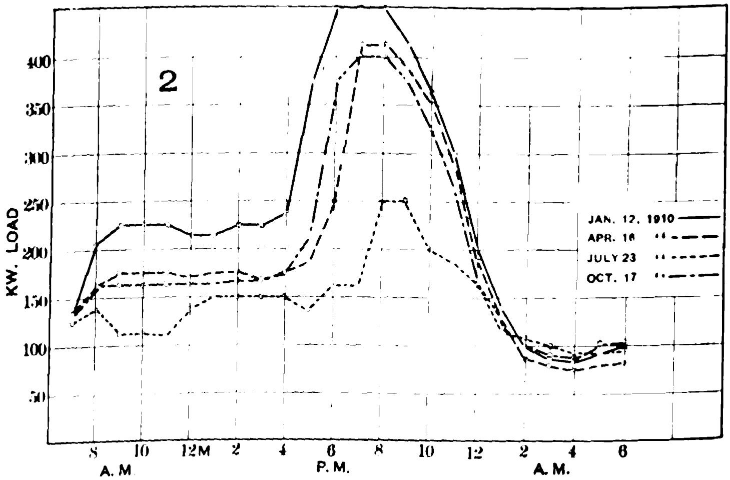
is 17 stories above ground and two below, built on a plot approximately 210 by 205 ft. (64 by 62.4 m.). This building contains housekeeping apartments, as well as the ordinary hotel rooms, restaurant kitchen and laundry.



Curve 1. -Hotel

Refrigeration is supplied to the housekeeping apartments, as well as to the kitchen and restaurant, and cooled drinking water is also circulated throughout the building.

The elevators (about 17) are all of the hydraulic plunger type,



Curve 2.—Apartment Hotel

operated by compound and triple pumps. The ground floor contains a number of handsome stores, brilliantly illuminated, while the rest of this floor is given up to public rooms and restaurant.

The approximate connected capacity of lighting is 750 kw. and the maximum load is 450 kw. from 6 to 8 p.m.

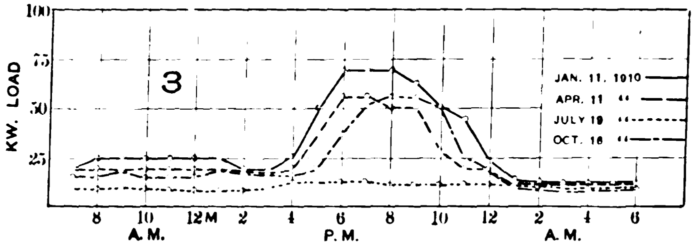
The ratio of maximum load to connected capacity is therefore about 60 per cent.

In this hotel the electric plant seldom uses over 300 h.p. during the day and 600 h.p. at night, whereas the boiler horse power developed frequently exceeds 1000.

The balance is made up of the steam supplied to elevator pumps, half a dozen other steam pumps, laundry, kitchen and refrigerating plant.

During the cold weather the exhaust steam from all the apparatus does not suffice to heat the building, and additional boiler steam is needed.

It is not unusual in the building to burn 40 tons of fuel in a day, and 50 tons have been burned in extreme weather. This latter consumption indicates an average of 1000 h.p. for the whole 24 hours. During the cold season it is evident that the electricity is really a by-product of the heating, in so far as the fuel is concerned. A distributive test showed that the electric plant used about seven-eighteenths of the total steam supplied.

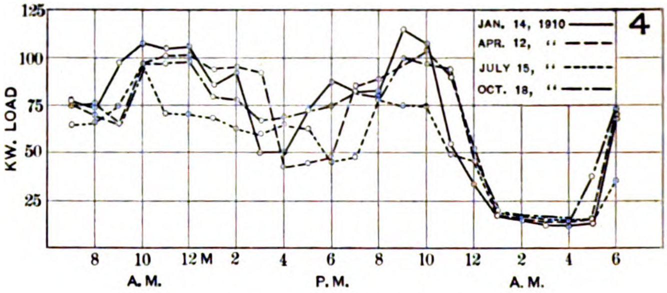


CURVE 3.—APARTMENT HOUSE

Curves 3, 4 and 5 show conditions in high grade housekeeping apartment houses. The three curves represent different conditions.

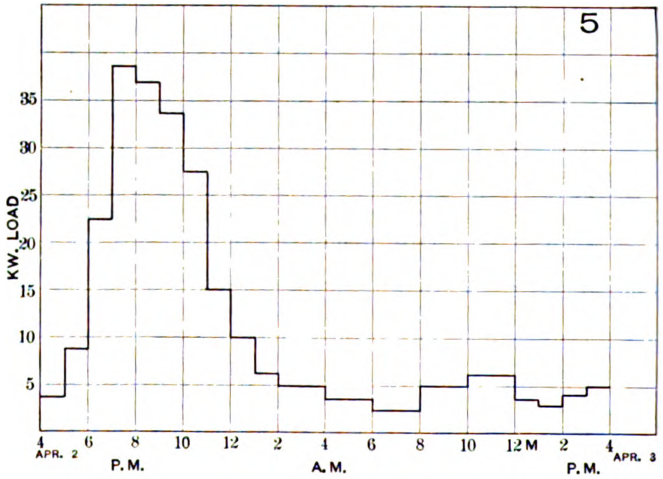
Curve 3 is an apartment house in which electricity is supplied free with rent. The refrigerating plant and pumps are steam driven. The building is twelve stories and basement, and the apartments are large, 34 in all which rent from $3,000 to $4,000 per year. The building has its own electric and refrigerating plant, electric elevators, but no storage battery.

The curve shows the steady load, and elevator fluctuations are additional and reach as high as 30 kw. The connected capacity excluding elevators is 100 kw. The ratio of maximum load to connected capacity is 70 per cent.



Curve 4.—Apartment House

Curve 4 is from an apartment house of the highest class, in which electricity is sold to the tenants at the standard central station rates, although made on the premises. The building covers a block 200 by 100 ft. (61 by 30 m.), 12 stories and basement, containing 48 apartments. The different character of this load curve is largely due to the operating of an electrically driven, 15-ton refrigerating machine. A large storage battery acts as auxilliary to the electric plant, and at one o'clock every

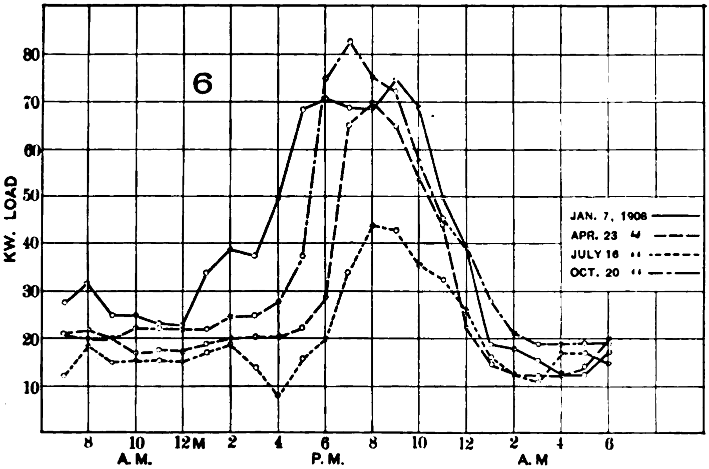


Curve 5.—Apartments

morning the engines are stopped and the electricity is supplied from the battery.

Curve 5 is an apartment house, two elevators, with 72 apartments, which rent for about $280 to $300 per room per year. The building covers a block and has 8 stories and basement. The maximum load is 38 kw. exclusive of elevators, and the connected capacity about 100 kw. The ratio of maximum load to connected capacity is about 40 per cent.

Curve 6 shows the electric load variations in an apartment house of the best grade. The apartments are of from five to fourteen rooms, renting at from $1,000 to $5,000 per year. They have artificial cold storage, complete porter service and a vacuum steam heating system among the "modern improvements." There are seven electric elevators for eighty-seven apartments.



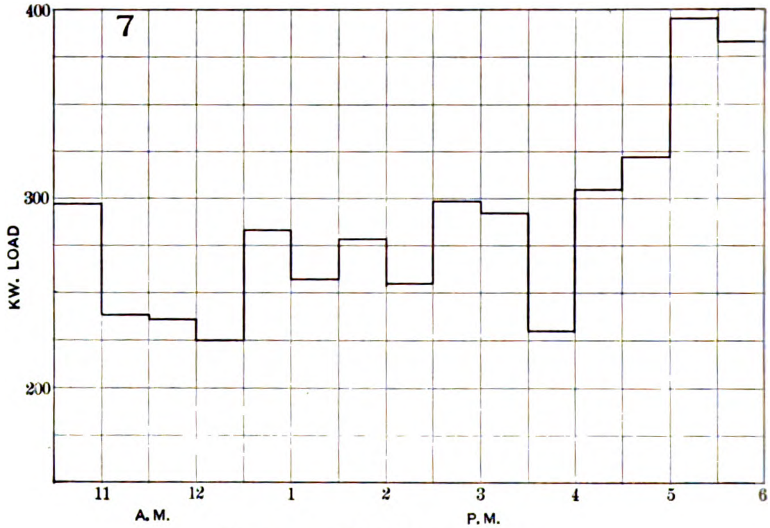
Curve 6.—Apartment House

Electricity is made on the premises, but it is sold to the tenants at the regular central station rates after being metered.

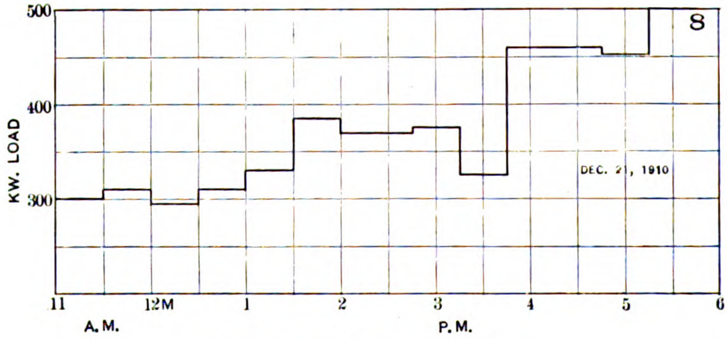
The connected capacity exclusive of elevators is over 200 kw. and the maximum load is 75 kw. (The 82-kw. load on October 20, 1908, was due to special decorative lighting.)

As this 75 kw. includes about 12 kw. battery charging current, the ratio of maximum load to connected load is actually about 30 per cent. The effect of metering is clearly indicated if the ratio of maximum load to connected load in Curve 3, 70 per cent, is compared with this ratio of 30 per cent.

Curves 7 and 8 are maximum load curves in two department stores in New York, catering to customers in moderate circumstances. The connected capacity was not obtainable but from installations in other department stores a ratio of 60 per cent may be safely assumed as the ratio of maximum lighting load to connected lighting capacity.



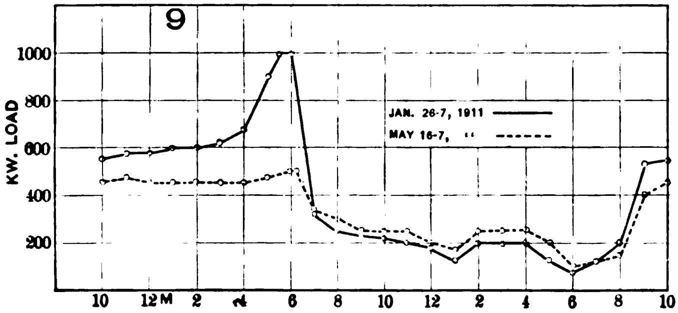
Curve 7.—Department Store



Curve 8.—Department Store

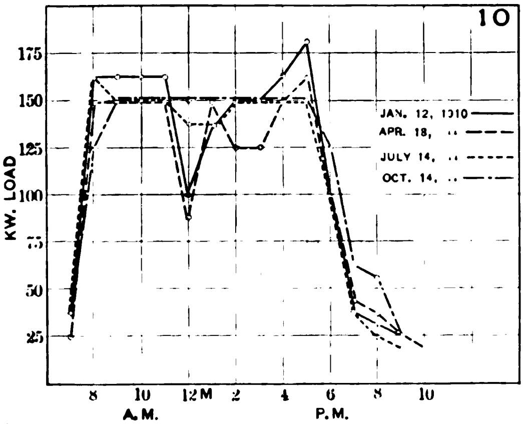
In so far as the power is concerned, the character of the service is all important. If the motors are connected to elevators, the maximum sudden, momentary demand with four or more elevators will not exceed one-half the sum of the rated starting currents, and where there is a large number of elevators, this ratio will drop to one-third.

Curve 9 is a load curve of a large dry goods store, taken on



Curve 9.—Department Store

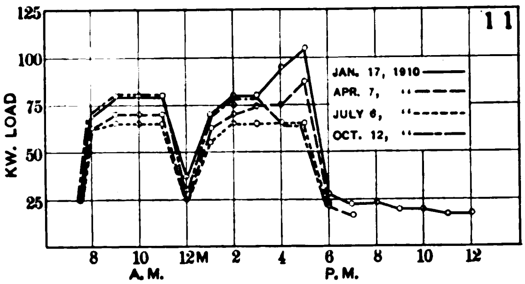
January 26 and May 16. The maximum load in December reached 10,000 amperes at 110 volts or 1100 kw. The connected capacity, excluding spare apparatus such as a second motor for driving a reserve exhauster for cash system was over 2,000 kw., or omitting the motors, approximately 1,600 kw.



Curve 10.—Loft Building

The ratio of maximum lighting load to connected lighting load is in this store somewhat less than 60 per cent. Curves 11 and 12 are typical of loft buildings devoted to light manufacturing, such as shirtwaists, cloaks, suits, lingerie, etc. Curve

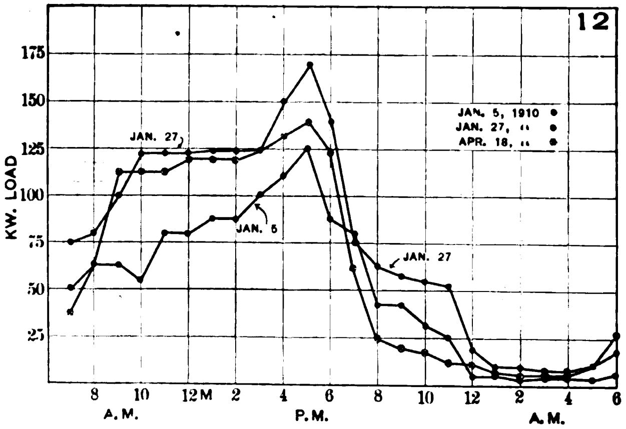
10 is from one of the oldest and best known of the modern 12 story buildings. It is 185 by 200 ft. (56 by 61 m.) and enclosed on two sides, having twelve elevators besides four sidewalk lofts.



CURVE 11.—MANUFACTURING LOFT BUILDING

The curves show the steady load, the fluctuation due to elevator load being additional.

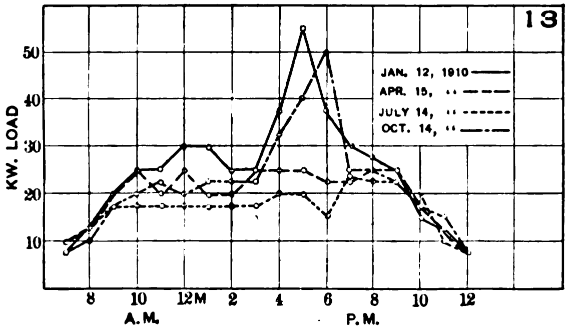
Curve 11 is from a similar building on a corner 100 by 100 ft. (30 by 30 m.) 12 stories, with four elevators.



CURVE 12.—OFFICE BUILDING

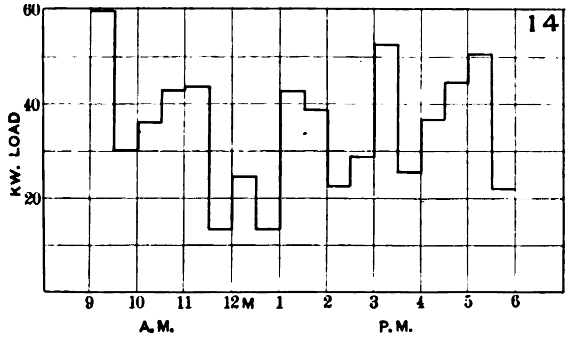
Four floors and the basement are occupied by the owners of the building, and are used for the manufacture and display of holiday goods, picture postals, etc. The other floors are leased, three to a printing firm. This firm's use accounts for the night load.

The connected capacity in these buildings is 251 kw. motors plus 336 kw. elevator motors and 214 kw. plus 100 kw. elevator motors respectively, and the ratio of maximum load and connected capacity is 36 per cent for building No. 11 and 35 per cent for building No. 12.



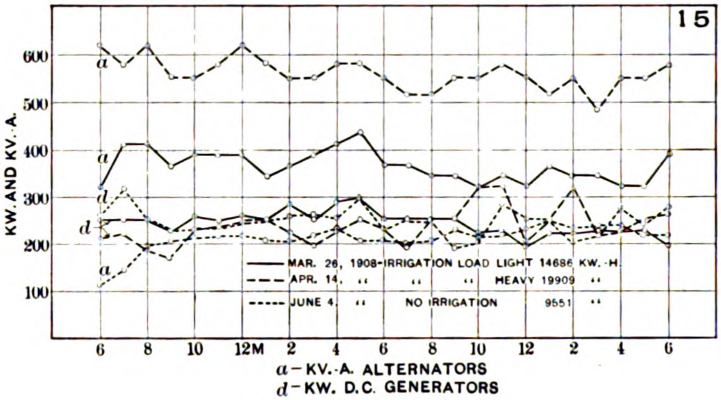
CURVE 13.—OFFICE BUILDING

Curves 12 and 13 are from typical office buildings. Curve 12 taken January 27 and April 18, includes the electricity supplied to a 12-story building 50 by 100 ft. (15 by 30 m.), abutting into the south. (January 5 curve covers the original building only.) This building contains five elevators and the abutting building contains three. These are supplied through a storage battery and the load curves include about 25 kw. of charging current. The ground floor basement is occupied mainly by a restaurant and a store. A very complete electric-driven ventilating equipment is installed for both of these.

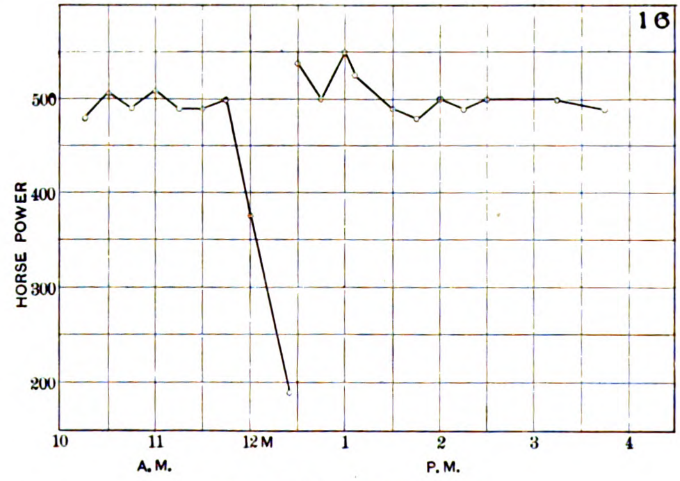


CURVE 14.—MERCANTILE BUILDING

Curve 13 is from another office building on a corner 100 by 100 ft. (30 by 30 m.) and has four elevators but no storage battery. This load curve shows steady load as nearly as possible. The connected capacities are 375 kw. and 212 kw. respectively, and the ratio of maximum load to connected load is 44 per cent and 26 per cent.



CURVE 15.—SUGAR MILL



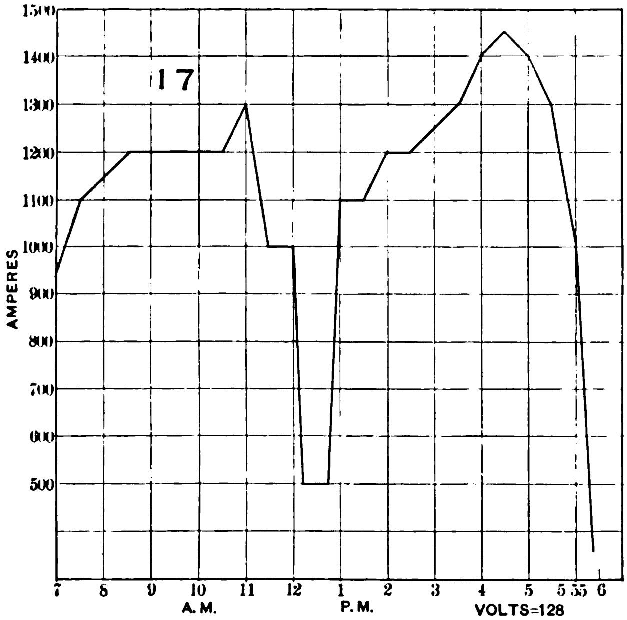
CURVE 16.—JUTE MILLS

Curve 14 is a typical load curve of a mail order house. The elevators are hydraulic plunger type, so the curve shows the electricity used for lighting and for the operation of sewing machines, phonograph motors and other small motors.

The connected capacity of this installation is approximately 188 kw., and the ratio of maximum load to capacity is 32 per cent.

Curves 15, 16 and 17 are industrial load curves.

No. 15 is from the immense sugar mill. No. 16 is from a jute mill and No. 17 from a malleable iron foundry. (The last represents only the load of a producer gas engine unit and cannot be taken as the whole shop load.) It is given here merely for illustration.



Curve 17.—Iron Foundry

Load Curve Characteristics. The electric load curves of the hotels show a daily running load from 8 a.m. to 3 p.m. of from one-quarter to one-third the maximum load, and a peak load from dusk to midnight or 11 p.m. of from one-half to full maximum load, depending upon the season.

The apartment houses where electricity is paid for, show a day load, deducting charging current of from one-seventh to one-eighth. The maximum load with the usual peak from dusk to 11 p.m. of about $\frac{3}{4}$ maximum load, except in summer when it falls to one-half. When light is included in the rent, the day load varies from one-seventh to one-third the maximum, and the peak load except in the summer is about three-quarters of the maximum.

The department store shows a steady day load from 9 a.m. until 4 p.m. in the winter; and until closing time in the other seasons of about two-fifths; the maximum load and the night lighting for cleaning, etc., vary from one-fifth to one-tenth the maximum.

The office building without restaurant has a day load of from one-third to two-fifths the maximum load, and there is no peak except during the winter and fall months.

The office building with restaurant and ventilating fans has a day load of about two-thirds the maximum, and the peak load lasts about two hours.

The manufacturing loft building has a steady load except during the noon hour of three-quarters to seven-eighths of the maximum. The lesser load during the summer months in one case is due to the stopping of the printing plant. The peaks seldom last longer than one hour.

The industrial plants have similar curves, *i.e.*, steady load with comparatively small peaks for about an hour.

With these load curves and others, as a basis for design, the division of the isolated plant into suitable units is not difficult, if the probable tendency of the building can be gaged in advance. In the following discussion, a unit is intended to mean an engine dynamo, with its switchboard, piping and accessories.

For a hotel or apartment house a three unit plant, each unit having a capacity of half the maximum demand, will leave one unit always in reserve; one will operate the equipment during the light load periods, and the two during peak load with good over-all efficiency and perfect reliability. If electric elevators are installed, a storage battery to equalize the fluctuations while the dynamos are operating and to carry the small lighting load from 1 a.m. until 6 p.m. while the dynamos are shut down is a valuable and advisable adjunct, not only as an economizer of fuel, but also to insure freedom from voltage variation.

In large plants like that of the hotel illustrated in Curve 2, it may be advisable to make the plant a four-unit plant, two of the units having each one-sixth the capacity required for the maximum demand. One of these operated after midnight will then supply all the service.

In the loft and manufacturing buildings, two large units, each capable of carrying the full load, and one small unit for after-hour service, is advisable unless the fixed charges on the extra initial cost of the two large units over a three-unit plant with each unit equal to one-half the maximum demand, more than equals the saving obtainable by the operation of one unit instead of two.

As the cost of the two-unit plant is usually at least one-quarter more than the three-unit plant, this question requires careful consideration, but simplification and space conditions point *a priori* to the two-unit equipment.

The same conditions hold with department store equipments, but another factor of grave importance enters, *viz.*, continuity of operation.

Darkness in a department store during a busy season might cause a panic and would almost certainly mean loss, hence it is advisable to have two units actually operating during all the selling time, or at least during peak load period, so that if anything should occur to prevent one machine from supplying light, the other would be immediately available. Hence it is customary and advisable to have at least three large units and one small one for late night service.

Office buildings of the ordinary type come under the same grouping as the hotels and apartments. The peak is of much shorter duration, and one of the units may be of less efficient type than the two regularly operated engines, if the size of the plant makes such a distinction advisable.

A storage battery is particularly advisable in most office buildings that are equipped with electric elevators, because the elevator load is a very large and sudden addition to the regular running load, and even with the perfected modern mechanical and electrical governors, some fluctuation in the lights is liable to occur. Of more importance in this connection is the small but necessary night lighting and the power required for a night watchman's elevator service, for both of which the storage battery is admirably adapted.

For factories occupied by a single owner, a single unit plant is adopted in most instances, because of its simplicity and the usual reliability of the slow-speed engines and dynamos ordinarily adopted for such installations. Such an equipment has its serious drawbacks, particularly in starting a new plant, where some unforeseen and hidden trouble in manufacture may cause untold annoyance, if it develops after the regular running is commenced.

If ample time can be had to test out the apparatus beforehand, little trouble need be feared with a single unit where the schedule of 10 or 11 hours a day is adhered to.

POWER PRODUCTION IN ISOLATED PLANTS

I have already pointed out the influence of the different factors upon each other in the isolated plant. The choice of a prime mover is necessarily governed by these factors.

If heating is a negligible matter, as it is in tropical countries and in many manufacturing and industrial establishments, the choice of a prime mover is governed by the balance between investment and efficiency.

The high efficiency modern producer gas engine and the oil engine by their simplicity and reliability offer many advantages over the high pressure steam plant, and where steam is not used for other purposes to an extent proportioned to the power requirements, the tendency is rightly, I think, toward this type of plant.

Two producer gas engine plants recently installed have given results fully equal to the guarantees, and a kilowatt-hour can be and is regularly produced at the switchboard under regular operating conditions for about two pounds of No. 1 buckwheat anthracite or pea coal, and this in plants of a few hundred kilowatts capacity.

One of these plants, of 175 kw. capacity, of which the load curve is given, is making current for 1.14 cents per kilowatt hour, including fixed charge on a power house, etc., for a duplicate equipment. These are the owners' figures and include all charges.

The other plant, a 600-kw. plant, divided into three units is using 1.75 pounds of pea coal per kw-hr. under regular working conditions, including all fuel used for banking.

As the cost of the gas producer plant is no higher than that of a high efficiency steam plant, the relative merits under the conditions outlined hardly need elaboration.

On the other hand, in another plant, belonging to the same company for which the gas engine plant was installed, the steam engine offered the correct solution for at least part of the plant, because the electricity was practically a by-product of the concentration and evaporation of the sugar solutions.

In many instances a combined steam engine and producer gas or oil engine plant offers the best solution, the steam plant being installed to such extent only that its exhaust may be fully utilized.

With such equipments, with the exhaust gases from the gas engine used to heat feed water from the boilers, an almost ideal operating condition exists for at least part of the year.

I have investigated a number of isolated plants, operated by oil engines, and find particularly in the small plants that they are giving remarkable service. The almost universal testimony is to the absence of trouble and the reliability of the small sets. With the larger units the heavy parts and the unfamiliarity of the operators have given some trouble, but in general the results are satisfactory.

The necessity for steam boilers and the space conditions in city buildings usually preclude any type of plant but steam unless the building is planned from the inception for the gas engine or oil engine equipment. As the engineer is frequently not called in until the general plan is adopted and as space beyond a certain amount is often extremely precious, the usual isolated plant in city buildings in the East is a steam plant.

Costs of Making Electricity

Some kilowatt-hour costs in buildings follow: These costs are derived by deducting from the total operating cost of the building with an electric plant, the cost of operating without an electric plant. This latter cost is either actual or estimated, depending upon whether street service had been used prior to the installation of the private plant or not. In each instance the fact is stated. I do not go into particulars of each plant because there have been many such figures printed. They are however as closely correct as I can make them and are taken from the regularly monthly plant reports.

Where the costs are given for different seasons, the variation is due of course to the high cost of supplying heat and engineers services, etc., during the winter and the relatively low cost of these services during the summer.

The kilowatt-hour costs do not include fixed charges unless otherwise stated.

My reason for excluding fixed charges is that each case presents a different condition. Money may be worth 25 per cent to one man and 3 per cent to another. With the cost of making electricity before him, each man can then decide if this cost is sufficiently less than the central station charge to warrant the investment.

KILOWATT-HOUR COSTS

Loft building.—100 by 100 ft. (30 by 30 m.) 12 stories and basement.

Month	Kw-hr.	Total cost	Basic cost	Mfg. cost	Mfg. cost per kw-hr.
April	15080	756.81	300	456.81	$0.03
January	18450	936.26	470	466.26	$0.0252
October	17810	884.76	300	484.76	$0.0328
July	12060	680.26	200	480.26	$0.04

Cost of plant: $12,000. Fixed charges per kw-hr. approximately ¾c.

Loft building.—185 by 200 ft. (56 by 61 m.) 12 stories and two basements.

Month	Kw-hr.	Total cost	Basic cost	Mfg. cost	Mfg. cost per kw-hr.
April	36930	1830.25	750	1080.25	$0.029
January	41950	1841.82	950	891.82	$0.0212
October	39480	1643.07	750	893.07	$0.0226
July	31800	1543.04	650	893.04	$0.0281

Fixed charges: ½ cent per kw-hr. Plant cost, $20,000.

Apartment house: (free light); 36 apartments, high class refrigeration; best service.

Month	Kw-hr.	Total cost	Basic cost	Mfg. cost	Mfg. cost per kw-hr.
April	17450	1359.86	1016.85	343.01	$0.0197
January	21620	1360.84	1052.29	308.55	$0.0142
October	13500	1208.67	900.75	307.92	$0.0228
July	9350	1074.03	709.82	364.21	$0.0389

Apartment house: (Electricity sold to tenants; 87 apartments; high class refrigeration; best service; large quantity public lighting.

Month	Kw-hr.	Total cost	Basic cost	Mfg. cost	Mfg. cost per kw-hr.
April					
January	18154	2224.59	1749.18	475.29	$0.0261
October	14885	1920.56	1507.34	413.22	$0.0278
July	11254	1731.54	1226.66	504.88	$0.045

These items are all higher than usual because last year the plant was completely overhauled, new plates installed in storage battery, new condenser for refrigerating plant, new hot water tank, etc., all of which is charged off during ten months from date of expenditure.

Office building: 100 by 100 ft. (30 by 30 m.) 12 stories; tungsten lighting; four elevators.

Month	Kw-hr.	Total cost	Basic cost	Mfg. cost	Mfg. cost per kw-hr.
April	14600	738.15	365.62	372.53	$0.026
January	18310	714.39	458.40	255.99	$0.0142
October	15060	669.69	355.03	314.66	$0.021
July	11590	693.17	250.00	443.17	$0.04

Office building: 140 by 70 ft. (42.6 by 21 m.) 10 stories.

Total kw-hr. 340,000 of which 88,817 were used mainly for driving an electric pump for operating two high-speed plunger elevators. 255,788 kw-hrs. for lighting.

Total cost per year	$8,070
Basic cost (estimated)	$3,200
Cost of electricity	$4,870
Manufacturing cost per kw-hr	1.43 cents

MANUFACTURING PLANTS

Locomotive Works—oil engines.

Total cost per kw-hr. on 225 h.p. set (including 0.223 cent for fixed charges).......0.74 cent.

5300 hours a year at full load.

Shop time 6500 hours.

With load factor another year after panic, of only 24%, cost per kw-hr. was increased to.......2 cents.

Malleable Foundry: **Producer Gas Plant.**

Total cost per kilowatt hour including fixed charges approximately . . 1.71 cents.

Hardware: (Steam plant condensing). These figures include interest and depreciation and are given through courtesy of Mr. T. Hoops, Jr., Supt. of Wilcox Crittenden & Co., Middletown, Connecticut.

1908		
Month	Kilowatts	Cost
May	23,970	0.01986
June	27,760	0.01733
July	29,600	0.01602
August	27,530	0.01736
September	27,830	0.01601
October	26,180	0.02095
November	22,360	0.02289
December	24,960	0.02164

Silk Mill Producer Gas Plant. (New York City); 150 by 100 ft. (45.7 by 30 m.) 4 to 5 stories high.

In week's run of 56 hours . . . . 4208 kw-hr.

2.6 pounds of pea coal per kw-hr. approximate cost including fixed charges . . 2¼ cents.

Department Store: 2,500,000 kilowatt hours.

Cost per kilowatt hour . . . . 1.34 cents.

Hotel: (based on figures given by chief engineer).

Cost of operation with plant $33,285.71

Cost of operation without plant . . . .

Cost exclusive of electricity purchased 25,779.71

Cost of making electricity . . . . $ 7,407.00

Cost per kw-hr . . . . between 6/10 and 7/10 cents.

Hotel: 300 rooms; 12 stories; 240,000 kw-hr.

Total operating cost $12,800

Basic cost (based on operation before plant was installed) . . . . $ 8,600

$4,200

Cost per kw-hr . . . . 1.75 cents.

TABLE OF COST PER KILOWATT CAPACITY

(Based on personal experience in New York and vicinity)

	Per kw. of plant capacity
Boilers (erected and set in masonry):	
Horizontal-tubular	$14—$18
Water-tube	16— 20
Steam engines:	
High-speed, simple direct-connected	20— 25
Medium-speed, compound non-condensing direct connected	28— 35
Low-speed, compound condensing, belted	20— 25
Low-speed, simple, belted	25— 30
Gas engines	50— 60
Oil engines	75— 85
Gas producers	15— 20
Dynamos:	
Direct-connected to high speed engine	13— 16
Belt-connected to engine	12— 15
Direct-connected to corliss engine	16— 20
Switchboard	5— 10
Foundations	5— 10
Steamfitting—including auxiliary apparatus—such as feed heater, grease separator, exhaust head, tanks, covering, etc	20— 30

The figures of installation cost have been published by me before and I use them in estimating and find them to be closely correct for New York City.

I hope that these figures together with the other data presented will be of use and will also serve as a basis for discussion and presentation of other facts and figures.

CHICAGO CONVENTION CONFERENCE OF INSTITUTE OFFICERS AND SECTION DELEGATES

THURSDAY, JUNE 29, 1911

Mr. Paul M. Lincoln, Chairman of the Sections Committee, called the meeting to order at 9.00 o'clock P.M., and said:

Gentlemen: We are to discuss such matters of policy in regard to the Institute as any one may wish to bring up. There has been intimation from time to time, from some of our members that they would take exception to the way the Institute is managed. We want to give those gentlemen the chance to speak to-night.

According to the terms of our Constitution, the Chairman of the various Sections are the "official delegates" and they attend this convention as such. During the last few days these delegates have met in committee of the whole and have discussed some of the matters pertaining to the policies of the Institute, particularly the policies which have to do with the operation and welfare of the Sections. There have been some sub-committees appointed to take up specific subjects, and these subjects we hope will be fully discussed tonight.

One of the things upon which a sub-committee has been appointed is the extremely important matter to our Sections, of how best they may work harmoniously in parallel with other local engineering societies which meet in the cities in which they are located. For instance, in Pittsburg we have among others the Engineering Society of Western Pennsylvania and it is our desire to work in harmony with them. Other Sections have very similar conditions to meet.

Mr. Hoadley, of the Philadelphia Section, was appointed chairman of a committee to suggest methods for working in parallel with other engineering bodies, and we would like to hear from Mr. Hoadley.

George A. Hoadley: The relation between the Sections activities, local society activities, and other activities of an engineering nature that take place in the same locality has seemed to your committee to be an extremely important one. If we consider the whole engineering profession as productive of engineering energy—you might call it an engineering dynamo—and should consider all of these various societies that we have, part of them in one city, part in another, as running parallel, each taking its share of energy, we can see that in a certain way there would be a dissipation, rather than a concentration of energy. Now, it is the thought of the Committee that it is very desirable, indeed, that there should be a concentration of energy, partly from the fact that we as members of the different societies feel that if we attended all of the meetings of these societies we would hardly have time for anything else. Consequently it is, in a way, a matter of self-defense. Not only that, but we can get a greater effect, a better effect, we can secure greater results from our engineering work in Sections by coördinating our work with the work of other societies in the locality in which we live.

In a discussion that came up in the Section Delegates' meeting this morning, it was quite evident that each Section has its own problems to meet. One Section will have one group of engineering societies with which it can coöperate, another Section will have another group, and a third section may have almost none, and so it goes; each Section having its own individual questions to decide.

Now, it has seemed to your committee that perhaps the best way to present the results of the work that has been done, and the desirability of such work, was to call on some members of our Section Delegates where that plan has been followed out rather successfully. There appears to be a number of cases where it has been successful. In St. Louis, Professor Langsdorf tells us, the work has been carried out in a satisfactory way, and I think it would be very acceptable, indeed, to the members present, if Professor Langsdorf would give an outline of the work as carried on in St. Louis.

A. S. Langsdorf: In St. Louis we were confronted at the time of the organization of the Section with difficulties due to the existence of the Engineers' Club of St. Louis, a very strong organization made up of civil, mechanical, mining and electrical engineers, and for a number of years after the organization of the Section, in 1903, there was a great deal of duplication of work. About a year ago it became evident to a good many of us who were interested both in the Section and in the welfare of the Engineers' Club, that something would have to be done to limit the number of meetings which were scheduled, particularly in view of the fact that the members of the American Society of Mechanical Engineers had recently organized a section. Each of these organizations has interfered more or less with the others because of conflicting efforts to arrange programs. Finally, at the instance of the President of the Engineers' Club of St. Louis, a committee made up of representatives of all the organizations got together and drew up a scheme of coöperation which has now gone into effect and which promises very great success. The central idea of the whole plan of coöperation is to make the local club, that is, the Engineers' Club of St. Louis, the central body in the belief that if all of the engineers of the city can be made to work in harmony the best interests of the Sections and of the national bodies themselves will be better conserved. The plan adopted embraces a number of points, of which the first is that each branch of the national societies, that is the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, (and also recently the American Society of Engineering Contractors) agreed to schedule two of its meetings each year on regular meeting days of the Engineers' Club, and to furnish the program on these occasions, the meetings to be held under the joint auspices of the particular section and the club. Secondly, each branch is free to hold as many other technical sessions per year, in addition to these two meetings, as it chooses to hold, subject only to the requirement that all of the members of the Engineers' Club shall receive notice of such meetings, and shall be free to participate in the discussion. Thirdly, the Engineers' Club, to encourage membership in the national society, as well as to advance its own interests, waives the requirement of the usual initiation fee of $10 in the case of those applicants who, at the time of their application for membership in the Club, are members in any grade and in good standing of any of these national societies. Fourthly, the control of all joint meetings is in the hands of a Joint Council made up of representatives of the club and of the branches of the national societies, and, finally, the Meetings and Papers Committee of the Engineers' Club contains representatives of the national societies, so that all the programs can be drawn up according to some harmonious plan early each year.

The above, in substance, covers the plan of coöperation. It has not been in effect a sufficiently long time for us to be able to determine its ultimate value, but there is at the present time a far greater unity of purpose among St. Louis engineers than there has been in the past, and indications are that the scheme will work out very well indeed.

G. A. Hoadley: While it is practically impossible to get reports from all the Sections in this matter, we have such a good report from Mr. Powell of the Milwaukee section of the scheme that is in operation there, that I feel inclined to call on the representative of the Milwaukee Section for a description of the operation of that scheme.

L. L. Tatum: The problem in Milwaukee is substantially the same as that in St. Louis, except that we have not quite as large organizations to deal with. The Engineers' Society of Milwaukee has been in operation for some 15 years, it is on a fairly sound financial basis, and contains representatives of all the engineering branches. Before the Institute Section was formed, which was a little over a year ago, we cast around for some method of coöperation, and instead of forming an entirely different Section, making some specific coöperative plan, we have rented the clerical services, use of permanent headquarters and hall from the Engineers' Society. The members of the Section are not members of the Engineers' Society in any way, but are simply tenants in the use of the rooms. The fee of the Engineers' Society for their own members is an initiation fee of $5, and annual dues of $5. A fee for service rendered the Institute members was based on what we thought we could get, and it was made $3 a year; it made it a little bit cheaper than membership in the Engineers' Society, while it gave all the services. The Engineers' Society for that fee assumes all of the expense of the Section, except the expense of speakers, which was too indeterminate to put in any general agreement. The plan, as we hope it will work out eventually, will be to combine a section of the Mechanical Engineers, which will probably be formed this summer, and the Chemical Engineers, who have a very thriving branch. The Institute members have the right to two of the meetings, the same as in St. Louis, and if the other branches come in, that will take care, through the sections of the national societies, of six of our ten meetings, and the other four, which will probably be of a more general nature, will be handled by the Engineers' Society themselves. We have definitely provided in our agreement that a representative of the Engineers' Society Program Committee, be on the Program Committee of the Institute Section which is the same scheme Professor Langsdorf mentioned, except that this definite interchange is provided in our rental contract. The scheme, for the past year, has worked very successfully. The average attendance at the meetings of the Engineers' Society two years ago was probably between 40 and 50. The Institute membership in Milwaukee is about 100, 105, I think now, and the addition of the Institute membership has brought the average attendance at the meetings during the past year up to 90 or 100, with over 120 at two of the meetings. It has produced large audiences at the meetings, resulted in getting out better papers, in having better discussions, and has made the meetings very attractive.

We have in Milwaukee a very large contingent of young engineers—several concerns there are taking on a good many young students, and we consider it one of our problems there to get these young men into the game, bring them out, get them to work, and get them in shape to take active part in the work of the national associations. It must be partially an entertainment proposition—it is hard to get them together at the ordinary meetings, and it is very hard in the local Section to get out abstract papers of very much real value to the art, but if we can get out papers that will bring the young men into the discussion, and get them into the habit of going after questionable statements, or those with which their judgment differs, we feel our work will have been very well performed.

Chairman Lincoln: We have all of us heard considerable rumors, at least, possibly more than rumors, of some extensive coöperation plans which have been taken by the engineers of Boston. Just what part our Institute has taken in these plans I do not know, but we have a live representative tonight from the Boston Section, and we would like to hear from him.

N. J. Neall: I think that the essentials of what we have been doing is best put before you by our Chairman, Mr. Vaughan, who wrote for me, before I came away, some of the items he thought would be most interesting for me to bring to your attention. With regard to the query: "What are the best methods of coöperating between local Institute Sections and their local engineering organizations," Mr. Vaughan states that he favors our present plan, which is as follows:

"When a chairman comes into office in August he appoints a delegate to serve on a Joint Committee with similar delegates appointed by the Chairman of the local Civil, Mechanical and Engineering Societies to arrange a schedule of dates of meetings to prevent conflict and also to arrange for joint meetings for the coming year.

"Three joint meetings are so arranged, one under the auspices of each of the three Societies. The papers selected are, of course, of general interest, and discussion is invited from all the Societies.

"Further joint meetings may be arranged during the year if occasion arises, in which case such meetings form the regular meetings of the societies; also whenever a society has a paper which it believes to be of interest to one or both of the other societies, it invites their attendance in which case the society invited may or may not send out notices of their own.

"We all feel that a joint engineering club is badly needed, and would prove the best possible means of encouraging intercourse among the engineering societies. It would prove a decided force in the community, and it is hoped that the plans for such a club will be pushed through successfully.

"Our territory is at present limited to a radius of 60 miles, which seems wholly satisfactory and definitely sets the boundary of the territory in which the members take an active interest in the work of the Section. We consider this the proper geographical limitation to our present membership, with the exception of the Section members within a reasonable distance outside who express a wish to be kept on our mailing list."

"In connection with notices, it is believed that the local Sections should all have their notices addressed by the same addressograph, so as to prevent duplication of notices and to save expenses. Our society has made a considerable saving this year by contracting with an addressograph firm for printing all addresses, and we expect the other societies to follow.

"Every year in January the three societies hold a joint engineering dinner for the promotion of social intercourse and acquaintance among the members of the various societies and incidentally to forward plans for a joint engineering building which have been formulating here for several years. A joint committee is made up by delegates appointed by the chairmen of the three societies to make all arrangements for the dinner. The societies take charge of the arrangements in rotation. It has been the practice to have as guest of honor some leading representative of the Engineering Society conducting the dinner that year; for instance, the Mechanical Societies invited Mr. Westinghouse and the Electrical Engineers Professor Thomson. These dinners have been largely attended and a decided success."

Chairman Lincoln: This matter of coöperation between our Sections and other engineering bodies is, I believe, a very important one. I do not believe we can have good live Sections if they are going to be placed at cross purposes with the other engineering societies. We can only have live Sections when they work in harmony and in conjunction with other local engineering bodies. There are probably no two cases where all the conditions are exactly alike. We have had reports from two, and I know in Washington, D. C., they have rather peculiar conditions, and Mr. Wheeler, of the Washington Section, is here. I would like to call upon him to tell us something of the way they do things in Washington.

Earl Wheeler: The whole truth of the matter is there has been nothing done in Washington to bring about this phase of Section activity, but during the coming year we hope to bring forward some plan to coöperate with the Washington Society of Engineers, in a manner very similar to that which has been adopted by the St. Louis and the Milwaukee Sections. The Washington Section of the American Institute of Electrical Engineers was organized two or three years before the Washington Society of Engineers, but the latter society has a large membership, and more funds at its command than we have. Nevertheless we feel that we will be able to coöperate with them in at least two or three of their semi-monthly meetings. I think, with the coöperation of other members of the Washington Section, who are, of course, members of the Washington Society of Engineers, we will be able to bring this about.

The main trouble with the Washington Section of the American Institute, so far as I have been able to learn in the couple of years I have been interested in it, is the fact that they have never had a definite plan early enough in the year. I know that this last year, when the Executive Committee elected me to the Chairmanship, to fill a vacancy, that the entire Executive Committee, except myself, felt that we could not hold one single meeting a month and get out the membership; that is get out enough members once a month to have a good meeting. Our records show that after we started meetings in October on a definite schedule planned in advance, that the attendance at our first meeting was 65, compared to an attendance of about 20 in the previous years, while the attendance at our last meeting, in April, was about 175. With the coöperation of the Washington Society of Engineers, which we hope to get, I think we will be able to handle the matter very satisfactorily.

Another thing—I think that Sections located as the Washington Section is located, should plan to hold combined meetings of a couple of days' duration, with other Sections in the vicinity, and I think it will be possible within the coming year to combine with the Baltimore Section for a meeting to last over two days, and have the Institute officers there.

Chairman Lincoln: Mr. Pope, our Secretary, wants to contribute his mite to the discussion.

Secretary Pope: In practice of Sections in regard to coöperation with local engineering societies, differs with varying conditions.

One of the principal reasons of difference between the practice in different Sections is that there is a rivalry or jealousy, or something of that kind, due to the fact that they have not got together in the past. This feeling varies in different places. If we can get these engineers together, perhaps we can rub off some of the corners, and they will begin to learn that there is such a thing as an electrical engineer although he was scarcely recognized 25 years ago. I am pleased to learn that the Milwaukee plan has worked out so successfully. I felt a peculiar interest in it, because I was in Milwaukee and went over the plan with Mr. Tatum at the outset, and we then agreed upon the plan of having a regular yearly fee per member, to be paid to the Milwaukee Engineering Society, in lieu of bills for hall rent, stationery and various things, as is the practice in other Sections. It appeared that this would simplify conditions, and be more satisfactory to the local society, as the revenue would be more stable during the year, and it appeared to me that the result would be about the same; that the Milwaukee Section would pay to the local society per member about what it would cost the Institute if it paid the bills for these various services as they were rendered. Comparing the cost of running the Section on that plan, and the proposed plan with a flat fee of $50 for the Section and an allowance of $1 per year per member, and $5 for each entrance fee, it figured out very closely to the cost of the Milwaukee Section on the existing basis, so as an experiment I feel that the Milwaukee plan has been successful. Whether it will continue so another year, I cannot tell, for the reason that the Section has perhaps gained more members the past year than it will during the coming year.

I am not familiar with the character of the papers presented and their relation to local engineering topics. I have jotted down a few of the topics that all engineers should be interested in as citizens, and it has been one of my pet notions that these engineering problems in cities should enlist the attention of engineers in all branches. Take the electrification of steam roads, for instance, elimination of grade crossings, street lighting, the smoke nuisance, etc. There are other problems in cities in which all citizens, should be interested, and engineers are interested in them, not only as citizens, but by reason of their professional knowledge. The local pride in many cities is such, that a general local engineering society passing upon any one of these questions exercises a wholesome influence upon public opinion which a section of a single national society cannot exert. We have no Section in Salt Lake City, but there is a Utah Society of Engineers, in which our members are largely interested, and hold their share of the offices. As I told one of the Salt Lake members not long ago that they should organize a Section as a part of the local society and keep it up, with a Chairman and Secretary, as a skeleton organization, in order to represent the Institute as a Section. The same argument holds good with other societies, national in character, such as those of the civil, mechanical and the mining engineers.

The conditions in Cleveland, when a Section was talked of there three years ago, were somewhat similar to those which existed in St. Louis; the Electric Club was so strong that it was not thought advisable to establish a Section of the Institute. Those conditions have changed and we now have a Section there.

Two years ago a meeting of the Washington Section was called for the purpose of dissolving the Section. I went down and attended that meeting, and we talked over a plan for the future. I maintained that it was to their interest to continue the organization, even if they held no meetings; that at all events the Section should be maintained with the hope that interest could be developed. The very fact that the meeting had been called and held showed the advantage of having the organization, so that the Secretary could send out notices. Since that time, interest in the Section has been revived as shown by the largely increased attendance. If you do not have a really live Section, keep up the organization at all events, and interest may be developed in the future. The Institute, as a national organization, keeps you together in spite of yourselves, so that all that is necessary is for you to organize with proper officers, and if you cannot keep your own list of members you can obtain from the New York office in 24 hours a set of cards giving the addresses of all the members in your territory, so that it is really a simple matter to keep up a local organization.

The social features at the different gatherings of the Section members are very important, for the reason that you can get a good many people out to a dinner, or a smoker, who will not attend a formal meeting. Among the Section dinners I have attended are Boston, Schenectady, Pittsfield, Philadelphia, Los Angeles, Portland, San Francisco, Atlanta and Seattle. Of course, I did not take them all in at once, but in series. Some of them came pretty close together, for instance, San Francisco and Los Angeles. It would not do for me here to say that any one of them was better than another, because all of these Sections are represented here, but I wish to say this—that all of them have been exceedingly pleasant occasions, and it has been very inspiring to me to meet our members in different cities and feel that there was the same good fellowship existing everywhere. I feel that these informal affairs are working great good in establishing a wider circle of acquaintance. I have frequently cited the instance of Philadelphia, because I was there at the first meeting, where there was an assemblage of about 60 members and they did not appear to be acquainted with each other, but that has all gone by. They know each other now and they work together, and the Section has been flourishing ever since it started.

Another successful kind of meetings or events is excursions to plants. I notice that the Washington Section had an excursion to Great Falls, and there was an excursion from Toronto to the Niagara plants, and an excursion from Seattle to a distant hydroelectric plant. Such trips are very good for getting people together. This bears on another question which should be considered, which is the frequency of meetings. Sometimes the Sections try to have too many meetings. If you cannot hold successful meetings each month, hold them quarterly. That is one of the troubles in Washington which is permeated with societies of different kinds, and if a man undertook to go to all of their meetings, he would have no opportunity to spend an evening at home. A local list of members of all the societies in Washington is published and circulated which seems to be very useful. This catalogue gives the names and addresses of each member of all of the scientific or engineering societies in the city. The Washington Section has entered into that arrangement, as it does not involve any expense.

I will close with a few words about the use of Institute papers sent out to the Sections. We are quite willing to send them, if they are made use of, and I know they are used in some cases, but we do not wish to send them out if they are wasted, as it involves some expense and trouble, and there are a good many of them that are hardly suitable for a local meeting as they are not adapted to the audience. A paper on design for instance is not appreciated outside of a manufacturing centre.

Earl Wheeler (by letter): I wish to go on record as opposing Mr. Pope's criticism of the previous inactivity of the Washington Section, being due to an effort to hold too many meetings. I sincerely believe that there is more Section activity smothered by the absence of a short schedule than there is by too many meetings. I do not believe that wide-awake Institute members will stand for a hit or miss system of Section management. Furthermore no matter how many engineering societies or organizations are located in a given section, if the majority of the members of a Section cannot afford to lay aside one evening per month to spend on Section affairs, it is a good sign, in my mind, that the Section is in a state that calls for drastic measures of the Sections Committee.

I do not mean to state that the majority of members and associates of the Institute should necessarily attend all local Section meetings, because no Section can be active and efficient if it depends upon the somewhat limited number of full members and associates located in that Section. A live Section must have a large local membership to be active, and in the majority of cases I believe this local membership can only be obtained and held by active monthly meetings throughout the Institute year.

Another thing is the definite schedule of meeting dates. I think this should be fixed early in the year and definitely announced. It should be maintained, even to the extent of producing emergency speakers or papers, when for any reason whatsoever the planned meeting has failed.

Chairman Lincoln: Now, gentlemen, I want to throw the meeting open—not only on this matter of methods of coöperation, but everything else you have in mind that you want to say anything about. Mr. Pope has opened up a deep mine here in mentioning the possibilities of a New York Section. Undoubtedly, there will be some one who will have something to say on that matter.

E. Leonarz: I would like to ask one question—could not we, instead of making arrangements in the different locations with the different national societies, have a general understanding between the societies in New York—could not there be a possibility of a working agreement between the chairmen and directors of these different societies, so that a general working agreement could be reached. In our own case, in Mexico City, we would probably be able to get for the different societies a building, or at least a room, in which we could get together every month, or whenever it would be convenient. At present we have to hunt every time for another place, for another location, we cannot get one room and keep it for all the time. I think there are many other locations in which the same plan would work, or could work, better than any special agreement, which would have to be reached always between the local Boards.

Ralph W. Pope: I would like to say a word on the question of meeting quarters for the Sections. Mr. Leonarz has brought up a very important question in regard to the holding of meetings, and that is suitable halls, rooms, or buildings. There is no doubt but what that is a serious problem in a good many cities, because I have had a long and weary experience with it in getting halls in New York. One of the difficulties about halls is that the ordinary hall is not a very good-paying investment. You may have heard that Madison Square Garden in New York is to be torn down for the reason that it does not pay, and perhaps the Engineers' Building might be torn down if we depended on the revenue received from renting our halls, in spite of the size of the building and its accommodations, and it is for this reason, I presume, that it is difficult in many places to get suitable halls at a suitable price. This is another case where coöperation comes in, because if there are different societies, holding meetings on different nights, there is greater revenue in such a case than there is from a society occupying a hall all by itself. That means that one society has to carry the entire burden, and that the hall or quarters may be vacant seven-eighths of the time, or even a greater proportion. While we have solved that problem in New York by having a building given to us, the building would not be a revenue producer, as far as operation was concerned, if it was not for the location there of the offices and headquarters of different societies. The renting of rooms for meetings is a very small proportion of the revenue, but it appears to me that all of our large cities should have some gathering place of that kind, something equivalent to what we have in the Engineers Building. One of the difficulties we experienced is that we are not permitted to advertise the fact that we have offices and meeting rooms for rent, at least we think we are not permitted to do so—we are not sure. The question came up three or four years ago and it was decided that it was not ethical, and so we have not done it, but the result of the renting of the rooms for meetings has been such that it indicates that the building fills a want in New York City. In the course of three or four years, I presume we will be receiving a considerable amount for the use of these rooms for meeting purposes. If any of the delegates have any suggestions or any experiences in regard to this matter, I am sure that the other delegates will welcome the information. I might add that this problem has been solved in some of the cities through the liberality of some of the local public service corporations in equipping rooms for welfare purposes, for the use of their employes in holding meetings. I think that is the case in Boston, Philadelphia, New York Milwaukee, and perhaps some other cities.

Chairman Lincoln: We were to have had, as our first speaker this evening at this session of the Convention, our President, Mr. Jackson, but owing to reasons which I explained, he was unable to be present at the opening. Mr. Jackson will now address you.

ADDRESS OF PRESIDENT JACKSON

There are certain things that I desire to talk about to you as Section delegates.

To begin with, the American Institute of Electrical Engineers has as its main object the stimulation of the professional spirit among the electrical engineers of the country. It was that view that led me to direct my opening address of Tuesday into the channels which I did. The functions of the Institute are those of which I spoke in New York at the first meeting in my administration.

There are three main functions:

First, the finances, which under the Constitution are controlled by the Finance Committee, and which have for their object the support of the other activities of the Institute.

Second, the presentation and recording of papers denoting the state of the art of electrical engineering and signalizing improvements and discoveries made in the art, and also the preservation of historical records. This has for its objects sustaining the welfare of the profession and advancing its interests through advancing knowledge. These matters under constitutional provision are in the control of the Meetings and Papers Committee, the Standards Committee, the Library Committee, and the Museum Committee.

Third, the guardianship of the professional status of electrical engineers. This is in the control of the Board of Examiners, special committees on subjects like Engineering Ethics or Engineering Relations, and the Law Committee. We have had during the past eighteen months a Committee on the Relations of Consulting Engineers, but that committee has not made a report. The Directors have not authorized a Committee on Ethics, to see whether something cannot be done to outline our status more effectually. That was tried several years ago. but the movement was too early, and no results came of it.

All of these functions and activities are under the control of the Board of Directors; and the President, by the Constitution, is given general supervision of all the affairs of the Institute. The Institute management is largely by Committees. The Board of Directors are now trustees for some 7,200 members. The number was 7,117 on April 30 and is increasing rapidly. The present administration took the ground that it is not desirable to make an effort to increase the membership but that it is desirable to do all we can to assimilate our membership and get it effectively organized. But nevertheless, we had a net increase of 436 members. There are also several thousand students enrolled.

The Board of Directors are the Trustees for all that great membership, which represents the professional body of the electrical engineers of the land. The Board of Directors are your Trustees, the trustees of all the great membership, and I want to say that they do their part as trustees with remarkable fidelity. The Committees of the Institute also do their part with remarkable fidelity.

It is sometimes charged that the government of the Institute is a New York affair. That I will deny. The Board of Directors and the various Committees are most representative sets of men. One member of the Board has come from near Chicago to monthly meetings in New York without missing a meeting in the entire year of this administration. In fact, the men from the far parts of the country are as likely, and perhaps more likely, to be regular in attendance upon the monthly Board meetings, as the New York members. The Standards Committee is made up of men that hail from Milwaukee eastward, and these men have been very constant in attendance, month by month, on meetings of their Committees. The same is true of other committees. These things show a remarkable professional sentiment. And I therefore ask you, when considering the affairs of the Institute, to remember that you are dealing with the affairs of an organization that has an admirable set of Trustees who act with great fidelity and give their time and their traveling expenses without stint.

The Board of Directors during my administrative year is composed of members from six States and the Province of Ontario, and twelve of the members are from outside of New York City. These twelve members come from ten different cities. The new Board, which comes in with the new administration on the first of August, will be composed of members from nine States and the Province of Ontario, and the twelve members from outside of New York City (crediting the new President to New York City) come from eleven cities. The Board is composed of twenty three members, of which the Secretary and the Treasurer are naturally chosen from New York City and have been reëlected each year for many years. If the members desire a still wider territorial representation on the Board, they must use their powers of nomination more fully or else change the Constitution so as to give the Board a freer hand or to establish a Nominating Committee. Also, when about to make nominations the members should not use the process as mere compliments to the nominees or to forward section prestige without thought of whether their nominees will or will not attend the meetings of the Board.

The meetings of the Board must ordinarily be held in New York City because the records of the Institute are kept there at headquarters. It is important to have enough members of the Board from New York City, in order to insure a quorum at every meeting of the Board and the management of the Institute would inevitably fall under the domination of the New York members if members from other parts of the country were elected without regard to their willingness and ability to attend the Board meetings.

I present this point so fully because the members of the Institute apparently do not understand the importance under our present constitution of nominating for office only those representatives who can and will attend Board meetings. There is a wide representation of the area of this country, and therefore of the general membership, now on the Board, but this can be enlarged if the members will be judicious in making their nominations.

There is another thing for you, as Delegates, to bear in mind. The Board of Directors are limited in their actions in behalf of Sections as well as in all their other duties by the provisions of the Constitution and By-laws. The latter may be changed by a concurrent vote of not less than twelve members of the Board, following certain formalities; but the Constitution can only be changed by a vote of the membership. Consequently, if you do not always get what you want, look in the Constitution and see whether you are justified in asking for it without first invoking the machinery leading to a constitutional amendment.

I now come to the financial side of our problem. This Institute is an organization with really large interests. It has net, clear, unincumbered property of over $600,000. We are indebted to Mr. Carnegie for a good part of that, in the form of our one-third interest in the United Engineering Societies Building. The land on which the building rests is our own by purchase, and we still owe $54,000 on that, but we have investments in bonds which we could set over against that $54,000, and we would still have an ample balance.

The Institute is in admirable financial condition. The total money paid into the Institute for the year ending April 30, 1911 was a trifle over $97,000. The estimated income was $95,000 for the administration year, which ends July 31, 1911. The Chairman of the Finance Committee tells me it is going to exceed $100,000. It was estimated that the headquarter's expenses, which include printing, preparing and shipping the PROCEEDINGS and TRANSACTIONS, paying for meeting expense at regular Institute meetings and conventions, and the like, would come to about $65,000. This left an estimated amount of $30,000 for other uses during the administrative year.

We have many Committees, like the Standards Committee Law Committee. Library Committee, etc., that have expenses. The Standards Committee must have its report printed. The Board at its meeting on Tuesday last adopted a new Standardization report, modifying the old one, and it will be printed and issued to the members at an early date. That is Standards Committee expense. The Law Committee must confer with legal counsel, and that means expense. The Library Committee must pay its share of the Librarian's salary, which is divided between the three founder societies occupying and owning the United Engineering Societies Building, and other library expenses. There are also other committee expenses. The Committee expenses come in to take about one-third of that $30,000.

The Board of Directors, as your Trustees, found it was desirable to transfer another third of that sum to the Surplus Account. As an actual fact, the income will be larger, and, as I understand, we are this year going to put $16,000 into the Surplus Fund.

We took the remaining third of the $30,000 and gave it to the Sections. This is twice as much money as the Sections have had allotted to them in previous years. The Sections Committee has been one of our most active and effective Committees, and they are working out a plan whereby the Sections may be fairly and uniformly treated in respect to finance and to the assignment of Institute meetings. You should understand that Sections, in case they can produce the class of papers which is acceptable to the Meetings and Papers Committee, now have the right to hold regular Institute meetings, if they desire, such as have been last year held at San Francisco and at Charlotte, and this year at Los Angeles and at Schenectady and Pittsfield. The Sections this year were allotted for their purposes one-third of the funds that are over and above the necessary general running expenses of the Institute.

Finally, I wish to speak of the Secretaryship. We have a Secretary who is this year in his twenty-seventh year of consecutive service in the position of Secretary of the American Institute of Electrical Engineers. The older members of the Institute have a great affection for the Secretary, and particularly they have a great sentiment for the work he has done in building up the great body which is represented in the Institute today and we rejoice that this affection and sentiment seem equally reflected by the younger members. But when a man has been Secretary of an institution of this kind for twenty-seven years, having been a man in the prime of life when he started, he is certainly coming to a time when it is right for him to ask to be relieved of the burden of executive duties. That is true of our Secretary. Proposed amendments to the Constitution have been put before the members twice for the purpose of making it reasonable for the Board of Directors to meet that situation. These amendments have been lost. Notwithstanding that, Mr. Pope has come to us with a resignation. The Board of Directors on Tuesday night, when that resignation came up, accepted the resignation of the Secretary, to take place on August 1, and the Board immediately passed a resolution employing him on proper salary as Honorary Secretary, with supervision of Section affairs, under the direction of the Secretary and Chairman of the Sections Committee. I believe that sentiment will make that a permanent place for life. One of these days Mr. Pope will desire to be relieved from the duties of supervision of Sections affairs. He will want to retire to his rose garden, or back yard, or farm, or whatever it is, but still we ought to continue him as Honorary Secretary and give him such salary as may be reasonable and proper in the premises. (Applause). Now, I should like to have seen the amendments that were put before you this year duly carried, for the purpose of making it certain that no future Board could alter that situation, so that sentiment should be not only established by affection, but also established by law, but that, gentlemen, is your affair. Your votes determine that your trustees have done what they felt was desirable in putting the proposed amendments before you, and the trustees will do what the members order, because it is their duty.

Mr. Pope's resignation having taken place, the Board of Directors can constitutionally fill the vacancy until a Secretary is elected in due form at the next election, and as our elections occur only once a year, the Board of Directors will elect a Secretary to serve until August 1, 1913. But now is the time to remove a very serious embarrassment to the affairs of the Institute, and you can do this by carrying an amendment to the constitution so as to hereafter allow the Board of Directors to appoint the Secretary.

When the Institute was young, the processes of election were different from the present method, and when Mr. Pope went into office he was assured of re-election as long as he did his duty, as was right. That is true now of the Secretaryship of the National Electric Light Association, but our Constitution requires that the Secretary shall be elected by the members. Under this provision, any Secretary who has not had years of affectionate contact with the members is subject at any time to have a rival candidate run against him, and no able man. no man good enough for the position, who must earn his daily bread out of his day's work, would be willing to place himself in the position where he might be ousted from his living, although he might be doing the most admirable work, upon what may be called three months' notice, between the time when the votes come in in May, and the first of August, when the Secretary's official year ends. It will be difficult to permanently get the kind of man we need, under the present processes of election. The Board must be able to select your Secretary, and appoint him, so that he will be the Secretary so long as he does his duty to the Institute. That is a matter which fundamentally affects the welfare of the Institute. At the same time, the Secretary should be invested with the privilege of entering into the deliberations in the meetings of the Board, but under the laws of the State of New York, within which the Institute is incorporated, it is impossible for an officer appointed by the Board to have a vote in that Board. As a rule a single vote in the Board does not cut much figure. It is the benefit of the suggestions of the man, the brain of the man, his arguments, which are of value.

The Board of Directors has asked the President to appoint a Committee to coöperate with the President-elect for the purpose of considering candidates for the temporary position of Secretary, and to select certain candidates, one of whom may be appointed by the Board to fill the vacancy resulting from Mr. Pope's resignation. That man if he is the right man, will probably go on the Directors' ticket at the next election, and I hope that along with that ticket will go a proposed amendment to the constitution which may be adopted so that when the Secretary's term of office expires he may thereafter be appointed for good behavior by the Board.

I have spoken of the functions of the Institute and its present status. The future is for President-elect Dunn to speak to you about.

Chairman Lincoln: I wish to say that the Sections delegates, when assembled in meetings, have discussed this matter to some extent, and I think it is quite proper that the committee to which this question was referred should bring in its report at this time, so as to see what the consensus of opinion of that body of delegates was. This committee, you will understand, was appointed for the purpose of sounding the Sections delegates, and to obtain from that sounding of the delegates their consensus of opinion on this question as to whether the amendment which has been defeated for two successive years should again be submitted to the membership. Mr. McMeen, who represents the San Francisco Section, is the chairman of that committee. I will now ask him to make his report.

REPORT OF CHAIRMAN MCMEEN WITH REFERENCE TO RE-SUBMITTING AMENDMENTS

S. G. McMeen: The Committee, of which Chairman Lincoln speaks, held a session to discuss the subject, and by sounding all of the available members of the Sections delegates. At a meeting this morning, the subject was discussed at length and fully among all the Section delegates. It was found very soon in that discussion that the expressions of views of individual delegates were very similarly expressed and very similarly sought, and presently, upon the motion of Professor Langsdorf, seconded by Mr. Whitney, a unanimous vote was given, which I will read:

Resolved, That it is the sense of this meeting that the constitutional amendment relative to the manner of selecting the Secretary should be resubmitted to the membership for its decision; and that, further, it is recommended that such amendment be submitted in the clearest possible form.

The latter part of this vote was not at all intended, as I gathered from what was said by those who advocated that addition, as a criticism of any form which the proposed amendment might have had when it was before us before, and only in the hope that that, having been lost by a narrow margin twice, any possibility of misvoting, due to misunderstanding, might be this time fully removed.

The following further resolution was carried unanimously:

Resolved, That this meeting recommends that on account of the long and faithful service of Mr. Ralph Wainwright Pope as Secretary of the American Institute of Electrical Engineers, he be appointed Honorary Secretary for Life, at the salary he is now receiving.

Chairman Lincoln: Does any one wish to make any remarks on this report? The meeting is yours, and it is the exchange of views that will bring us light on this question.

RESOLUTION OF APPRECIATION TO SECRETARY POPE

A. S. Langsdorf: At the meeting this morning, on motion of Mr. Wagner of Fort Wayne, a Committee was appointed to draw up certain sentiments of the delegates, which, though not exactly in the nature of a resolution, are equivalent to one, and with your permission I would like to read the following:

The Section Delegates of the American Institute of Electrical Engineers, present at the Twenty-eighth Annual Convention, have learned of the resignation of Mr. Ralph W. Pope from the office of Secretary, and his appointment as Honorary Secretary, unanimously desire to place on record their grateful appreciation of the interest which he has shown in the welfare of the Sections, and of his unfailing courtesy in dealing between the office at headquarters and the Sections officers. They wish, further, to give expression to the high personal regard and esteem in which he is held by all of them, and to their satisfaction in the knowledge that the past friendly relations will be continued in the discharge of the duties of the new position to which he has been appointed.

This has been signed by Mr. Wagner as Chairman, Mr. Ford of Milwaukee, and myself, and I also have the signatures of the other delegates who were available.

Secretary Pope: It is hardly possible for me to refrain from expressing my heartfelt appreciation of this Resolution, which I feel sure, from the kindly words that have reached me at various times, is an evidence of the best of relations which have existed between your Secretary, the Sections, the officers of these Sections and the individual members. It is not possible for any one to interpret the feelings which I have had due to the fact that year after year I have received practically the unanimous vote for my continuation in the office of Secretary. Half of my business life has been spent in the service of the Institute. It became my ambition that the American Institute of Electrical Engineers instead of being the unrecognized organization it was at the outset, should reach the same standard, so far as numbers is concerned, of any other National organization. It has done more than that. It has reached the highest standard of progressiveness among the National engineering organizations. It was my ambition that every member of the Institute should receive from it a recognized value equivalent to the dues he paid. Many of the members fail to realize what it means for them to be identified with a national organization of the character of the American Institute of Electrical Engineers. It gives them acquaintanceship, it gives them prestige, it gives them a prominent standing in the profession, it enables them to rise from the unknown to the known, I could point out to you many of our prominent electrical engineers of today who have become prominent because of their association with the American Institute of Electrical Engineers.

Further, it was my ambition that the Institute should have a home of its own. It was my ambition that that home should be paid for. It was my ambition that when that home was paid for, that we would still be able to carry on our work and have surplus funds in order to do still more for the profession. All these things having been accomplished, I have known full well that the time must come when I must lay down the somewhat arduous, and yet pleasant duties in connection with this work, whether it was today, or next year, or five years hence. It appeared to me that it was best that I should retire from the office of Secretary under these circumstances, at a time when the Institute had reached that position of recognition by the general engineering profession. I am glad for my own sake that there is still something I can do to further the interests of you all, and so far as it is possible, I shall endeavor to continue in your affection and kind regards, so long as I am with you on earth. I thank you, gentlemen.

President Jackson: May I say a word more. The Board of Directors directed the President to appoint a Committee of the Board to draw up suitable resolutions expressing the opinion of the Board of Mr. Pope's work for the Institute, and the affection in which the Board holds him and has held him for many administrations. That Committee cannot well be appointed so as to have its resolutions presented at this Convention because it seems desirable to put upon it at least two of Mr. Pope's oldest friends, members of the Board, who could not come to this Convention, and are not in Chicago, and for that reason the resolutions are not yet prepared. They will be prepared and published in the PROCEEDINGS. I have a suggestion to make which, if the Delegates are pleased with it, I think would lead to our solidarity. It is, that when these resolutions are prepared they be forwarded to Headquarters and published in the PROCEEDINGS along with the Directors' Resolutions, and not given out at this meeting. Mr. Pope's resignation will be immediately announced at large, and the resolutions will follow in due time. I make that suggestion to you for your consideration.

Chairman Lincoln: I think we can say that the suggestion of the President will be carried out in that regard. I do not believe there is any intention on the part of the delegates to forestall any action by the Board, and if there is no objection, we will direct that that course be followed. It will be so directed.

The hour is getting late, and the President-elect seems to be somewhat later being detained at the dinner, that our President gave promise of—

President Jackson: He has been making a long speech.

Chairman Lincoln: There are two other Committees which were appointed by the delegates. It is not necessary that they report at this time, although if they have anything to bring up before the delegates at this meeting we will be glad to hear from them.

DISCUSSION OF METHOD OF ELECTING OFFICERS OF THE INSTITUTE

A. S. Langsdorf: The chairman asked me to act as chairman of a subcommittee to report upon the matter of the present method of electing officers of the Institute. The sub-committee held a meeting, and its recommendations were presented at another meeting of the Sections delegates held last night on the boat. While it was the unanimous opinion that the conduct of the Institute affairs under the present scheme of organization has been in the past, and is now, admirably and efficiently conducted, dissatisfaction was expressed at the method now in vogue, expecially because of the condition which now virtually precludes a representation in the Board of Directors of the Sections located at any considerable distance from New York headquarters. The President in his remarks has called attention to the fact that a considerable number of states, which have not previously been represented, are now represented in the Board of Directors, but to those of us who are western men it is obvious that New York does dominate the Institute, and there are a number of men, none of whom are anxious to hold office, who feel that if the Institute is to preserve its solidarity as a National body, there must be devised some way of securing representation of the outlying Sections in the managing body; otherwise there is the possibility of a split-off in much the same manner that dissatisfaction with the administration of the American Society of Civil Engineers led to the organization of the Western Society of Engineers.

The following motion was passed at last night's meeting (June 28):

> *Resolved:* That it be declared the sense of the Sections delegates present at this meeting that future elections be so arranged as to allow a contest for each and every office to be filled, that is, that the Directors' ticket, or its equivalent, contain the names of two candidates for each office.

It should be stated, in all fairness, that this was not a unanimous recommendation, the vote being nine affirmative and five negative. It was unanimously voted, however,—

> "That the Sections Delegates do not favor campaign methods of election, and that such practice be regarded as strictly unethical."

In the discussion preceding this vote, it was the consensus of opinion that the voters be informed of the candidates' qualifications by a plain statement of their respective records, printed on the ballot, and that no other campaign literature be sent out.

The sub-committee appointed to consider the general question of the election of officers also presented the following resolution for action:

> "The Sections delegates desire to present a vigorous protest against the present unchecked authority of the Board of Directors in controlling the selection of their successors in office under the terms of the existing Constitution and By-Laws. We feel that the Constitution must be so modified that the expressed wishes of large bodies of voters cannot be set aside. We recommend for consideration the election of Managers in accordance with some plan which will recognize the geographical and numerical distribution of members."

According to the best of my recollection, this recommendation was not voted on last night. At any rate, I cannot remember such action. but I would like to present it to the meeting for discussion, because I think it is the most important matter which the meeting has before it tonight.

N. J. Neall: There is a greal deal of constructive suggestion in this report of Professor Langsdorf just read, and I know, as a fact, that this method which is proposed of giving the records of candidates, is a very effective one. It is used in selecting term members to the Corporation of the Massachusetts Institute of Technology.

I am not prepared to say that I think the Board of Directors has been arbitrary in the exercise of its authority in the election of officers; but certainly this year it seems to me that the Board made a fair decision with respect to the probable helpfulness to the A. I. E. E. of its candidates for manager, so that if the recommendation which Professor Langsdorf has made would contain merely the suggestion that the geographical distribution and the numerical membership involved in a candidate's representation should be the controlling feature, and that the Board should be guided accordingly, I think our recommendation would get a great deal more consideration that it would receive if we tried to amend the Constitution. I think, rather than to commit the Sections and the board to a by-law which we might subsequently wish to repeal, that we would get better results by giving such a plan a year's trial.

One of the most serious problems, and I understand from President Jackson that he holds the same view, is to be assured that the men elected will attend the meetings of the Directors. Even those of us who would be interested, do not always have the time or means to come to New York monthly, especially if we live at a great distance, so that is a matter that in my judgment, should be approached rather cautiously. Broadly speaking, I think well of the suggestion that Professor Langsdorf has made, and if he will make it in the form of a motion I will give it my second, for official consideration by this gathering.

A. S. Langsdorf: I will make that motion, the last part of this statement here—

Chairman Lincoln: What is the motion you wish to make?

A. S. Langsdorf: It is not exactly in the form of a motion as it stands, and I had better read it again:

We recommend For consideration the election of Managers in accordance with some plan which will recognize the geographical and numerical distribution of members.

N. J. Neall: I second the motion.

Chairman Lincoln: The matter is now open for discussion.

Secretary Pope: Our election system certainly has its faults, especially in the way it has been practiced. It has the faults of all systems of direct nominations, unless there be some method of crystallization by which the members who vote in nomination, shall have a suitable method of expressing their views as to the candidates. The theory is, that each member shall express his own ideas about who the candidates for Manager should be, but there is no concentration of effort, the scattering result is such that we can really derive no information from it. This is a comparatively simple matter as regards the presidency, but when it comes to nominating vice-presidents and managers, it is hardly possible for people to give it the time, because their acquaintanceship is perhaps within a limited circle, and the consequence is that the nominations are so scattered that we may have two or three hundred different candidates for Managers.

L. L. Tatum: I am definitely opposed to the resolution as it stands. The arrangement of the geographical distribution can be made primarily by one Board, and becomes mandatory on the following Board, and it does not adjust itself to either the influence or the numbers in the different locations. I think we should have sufficient confidence in the integrity of our Board to know that they will use their best judgment in this matter, and a Board of twenty odd men can certainly look much more thoroughly into the qualifications of possible candidates than the total membership of some 7,000 men. I am, therefore, strongly in favor of leaving the selection of candidates to the Board of Directors as at present.

George A. Hoadley: I can see absolutely no reason why it ought not to be possible for our Board to give us an opportunity to vote—I mean really to vote—and that idea is brought out in the recommendation made, that two names be given for each member of the Board of Directors, instead of only one Directors' nominee. We know in any election which is held as ours is, that if a Directors' ticket is made up, giving simply four candidates for four offices, that that ticket is going to be elected. It is not in human nature to do otherwise, but if eight names are given, which have been selected from the votes that have been received, it then gives every member an opportunity to express his choice, but if four names instead of eight are given, there is no choice. I very much favor the suggestion which Mr. Langsdorf has read.

P. H. Thomas: I wish to call attention to the fact that under the present Constitution a second name for President and for Vice-president or Manager can be added to the so-called Directors' ticket, at the request of two or more Directors. If there is any candidate that any particular Section or district or territory would like to have put up, his name must go on the ticket, if they can persuade two Directors to ask it, provided of course the candidate had 3 per cent of the total number of nomination votes. Possibly that provision has been overlooked by some. I think when the methods of election were originally laid out, it was intended that when there was any dissatisfaction with the trend, or when any particular persons wanted any particular candidate added to the ticket, they should have this very simple and ready method available. If two members of the Board could not be found to ask for the placing of the additional name on the ticket, the assumption was that there was no sufficient demand for that particular candidate.

Chairman Lincoln: The question was debated at the Section Delegates' meeting as to whether the election of officers should be simply in the form of a mere ratification of some previous action, or should be an actual competition between two or more candidates. A vote was taken on that point, and the vote stood nine in favor of an election and five in favor of the ratification method. That is the way that the Section Delegates concerned looked at that question.

P. H. Thomas: I think the idea of laying out this election machinery was principally this—that if there were no differences of opinion amongst the membership, as there very often is not, it was not desirable to have two candidates, one of whom was going to very badly defeated, which would be humiliating to that candidate, and further the presence of two candidates would be an invitation to the campaigning methods to which many have objected. Personally I do not think we can have a contest without introducing these so-called "campaigning methods." So the endeavor was made to arrange the matter so there is no contest, and every one substantially agreed that the person selected the office was the right man, no one would be thrown down, and on the other hand if there was a real difference of opinion in the body of the Institute, as to who should be candidates, the provision was made that upon the request of two members of the Board of Directors, additional names could be placed upon the ticket thus protecting the minority. That was the theory, I believe, in the adoption of this election scheme, and it seems to me in theory it is a pretty good compromise, it has been in use a number of years, and I believe that it works out well in practice. If any of you want a special candidate, get together and pick out two members of the Board, and get your candidate's name on the ticket.

N. J. Neall: I did not second the motion about two candidates being proposed on the ticket for each office.

Chairman Lincoln: The discussion has drifted away from the matter in hand. The original motion was: That we recommend for consideration the election of Managers in accordance with some plan which will recognize the geographical and numerical distribution of membership.

J. B. Whitehead: As I was one of those in the informal meeting which we held last night who were opposed to the motion as Mr. Langsdorf put it, I think I had better say here in this larger gathering just why I placed myself in opposition. When this suggestion came up, I immediately asked why it was being brought forward, whether there was any dissatisfaction with the present method of conducting the affairs of the Institute; the answer was universally a negative one, even on the part of most of those who were in favor of the motion as Mr. Langsdorf has put it. It seemed to me, therefore, that it was very unwise for us to place ourselves on record as requesting specifically a geographical representation on the Board of Directors and Managers of the Institute, without also suggesting some mechanism by which we can either keep the conduct of affairs of the Institute at its present high state, or perhaps improve them. That is the reason I am opposed to the motion as it stands.

A. W. Berresford: As I am more or less a victim of the territorial distribution plan, I think my views may be of some interest. I believe I was elected a Manager of the Institute, not because of any prominence, nor because of notable work done in engineering, but largely because I lived in Wisconsin and was in New York frequently enough to attend the meetings of the Board.

My experience is that the Board of Managers is alive today to the necessity of territorial representation, is trying to get it, but must get it in such form as to insure proper attendance at the meetings of the Board of Managers held in New York City. The Board is an executive body and needs consistent representation from the membership for the consideration of questions which arise. In consequence, the men selected from widely distributed territory must be men who are selected, to some extent at least, with reference to their ability to go to New York and attend these meetings. A mere courtesy representation is of no real value and persistence in according it would ultimately operate to the disadvantage of the Institute as a whole. I believe this consideration has been the limiting factor and has been the reason for the choice of some possibly inferior managerial timber, such, for instance, as myself.

John B. Taylor: I think I understand the substance of the motion, but I do not understand the status of this gathering, nor to whom the recommendations in this motion are addressed. Is it that the Section Delegates are expressing an opinion to the Sections Committee, or is it the Sections Committee expressing an opinion to the Directors, or is it a Committee of the whole merely expressing their own opinion to themselves?

Chairman Lincoln: It is a method of getting the consensus of opinion of those who are present. This, as I understand it, is the idea back of the motion—What is the consensus of opinion of those who are here present? This resolution is simply a consensus of opinion, whether passed or defeated. Is there any further discussion?

D. B. Rushmore: I have not heard all this discussion, as I came in quite late, but after a few very pleasant years of experience on the Board, I appreciate the point of view of a person who sees from the outside what is going on, but does not have the opportunity of hearing all the discussion that leads up to certain actions. Mr. Berresford is quite right in saying that there has been effort to get as good geographical representation as possible, and I know when Mr. Black, of Toronto, was put on the Board, it was felt by all that Canada had a right to representation, and if Mr. Black gave assurances that he would come to the meetings, everybody felt he should go on the Board, and everybody spoke in his favor. Mr. Berresford is quite right in stating that the distance he is located from New York, namely, Milwaukee was very much in his favor, as he said he would be in New York every month, and could attend the meetings of the Board, and he has been a faithful attendant at the meetings. There is a great deal of work transacted at the meetings of the Board of Directors of which no one knows of many hours are spent in earnest discussion at these meetings, which occur usually on the same day with the monthly meeting of the Institute.

It has also seemed to me that the request for geographical representation is perfectly fair, and that the solution of this request must come in the future, and it will be a solution which will not be concerned with the monthly meetings in New York. It is quite impossible for a man in San Francisco or in New Orleans to attend monthly meetings in New York. The time when representatives of the different geographical divisions of the organization can get together will be at the Annual Convention, and as it is very likely to happen that there is to be a winter Convention in New York, that is most likely to be the time and the place for the gathering of the representatives of these geographical divisions, but this we were not quite prepared for—I do not know how many of you know it is proposed—but it is a fact that there has been a proposition made to give up the New York monthly meetings, and have a New York local Section, that is, put all parts of the country on the same basis, and in the course of time it will probably come—the indications are strongly in that direction. If that is done, certain legislative functions will be given to the representatives of the Sections, which they do not now have, and the actions which should be taken, the recommendations which should be made by representatives of the geographical divisions, will then have to be made at the Convention. If we are to have an active working force, which is to meet in New York as under present conditions, once a month, it is almost imperative that the members come from a certain limited radius, because their presence is necessary if they are to take an active part. While I am not authorized in saying this, it seems to me it will come, as the Sections grow larger and stronger, and we will see the Section representatives taking a more active part in the discussion of Section affairs at the Convention, that they will have given to them certain legislative powers, and that the deliberations of the Institute will then be taken at a meeting once a year, and what will happen to the present Directors it is hard to say. Certainly, under present conditions, where there is so much business to be transacted, the working force must be centered around New York City.

A. S. Langsdorf: The crux of the whole matter seems to be the claim that the work of the Institute cannot be effectively carried on unless once each month a body of twenty men get together for personal conversation in New York City. Those who are not familiar with the conduct of affairs question that dictum. Other organizations, with which many of us are familiar, manage their affairs very effectively, and with a far larger membership than the Institute has, by a system of correspondence, whereby the officers are not compelled to get together so frequently. The National Electric Light Association is such a body, for instance, and no one can deny it is very efficiently managed. A great part of the routine work can be and is carried on by the Secretary at the headquarters. The work which the Board of Managers of the Institute now carries on by personal conversation is in these bodies carried on by correspondence, and the question is whether or not a large part of the business transacted by our directors cannot be handled in the same way. I have been informed that a great deal of the work consists in looking over of lists of applicants for Associate Membership, and applicants for transfer to full membership, and I cannot see any reason why such work cannot be done as effectively by letter ballot as by word of mouth. There may be other work which needs personal contact, but the Executive Committee is already authorized to do that kind of work.

Chairman Lincoln: As I understand it, the passage of this resolution will simply put this meeting on record as being in favor of choosing the Managers with respect to their geographical and numerical location—are you ready for the question?

John B. Taylor: I am in sympathy with part of the resolution, and not in sympathy with another part of it. Apparently the resolution as drawn up originally, was not intended for presentation as a formal motion. We have had some expression of opinion on the subject, and I cannot see that this gathering, which seems to be a collection of the Section Delegates, with some others present by courtesy, can effectively vote on this and express anything for the large number attending the convention but not present at this meeting.

I move the motion be laid on the table.

E. A. Baldwin: I second the motion.

Chairman Lincoln: You have heard the motion, that the motion now before you be laid on the table. All those in favor of laying this motion on the table, which means postponing it indefinitely, say aye: opposed no. (The motion was apparently carried, but there were calls of " Division.").

The Chairman again put the motion, and it was found that nineteen members voted in favor and six members against the motion to lie on the table.

Chairman Lincoln: The motion is carried, and the motion which was before the house is laid on the table.

Gentlemen, I note that the dinner to which our President-elect had been invited this evening is over, so far as he is concerned, and he is now with us, and we will now have the address which was to follow President Jackson's address.

ADDRESS OF PRESIDENT-ELECT DUNN

My delay in arriving this evening has been due to the fact that I was in a difficult situation where my withdrawal, I felt, might seem discourteous and reflect unfavorably upon the American Institute of Electrical Engineers. With the best judgment at my command, I stayed, feeling that you would excuse me after I made this explanation.

In one way, I am glad that the motion that has just been presented was laid upon the table, not that I believe that these questions of improving methods of nominations should not be discussed, and in fact in the end should not be determined by just the men who are here tonight, who are most interested in these subjects, and who really represent the Institute, but because the question is an extremely complicated one, and can only be worked out after considerable study. It is hardly fair for me to come here, at the end of the evening, and to enter a discussion without knowledge of what has been said by the previous speakers.

I am frank to confess that on the question of the method of nomination I have not yet reached a definite conclusion—that does not mean that I wobble, but that several of these schemes are so new I felt I would be acting hastily on a matter of importance to the Institute if I at this time reached a conclusion. Why do we want to change our present method of nominations? One group of men says the electioneering methods used at present are offensive to us. The question of electioneering does not seem to me to be one that the Institute in general considers very seriously, because I find on the part of a great many members the recommendation that there be two candidates on the official ticket, what might be called a majority nominee and a minority nominee—the moment you accept that principle, and the moment you extend to the membership of the American Institute of Electrical Engineers the names of two candidates for President, and the names of more candidates for Vice-President than there are offices for Vice-Presidents, and likewise the names of more candidates for Managers than there are offices for such Managers, that moment you authorize the very electioneering methods that so many of the members find offensive. You make it a legitimate and accepted and necessary part in the nomination of every officer of the Institute. I am unable to determine what is the real sentiment of the Institute in regard to it. I must confess that about as many men have said the present methods are satisfactory in that respect as have said they were unsatisfactory.

I do not regard the question as the most serious one before us today and I would remind you that minority nominees are provided for in the Constitution. There is a serious question in the overshadowing importance that is given to the nomination and election of a President, compared to the nomination and election of the Vice-Presidents and of the Managers. The nominating votes for President run up into the thousands, the nominating votes for the other officers run up only into the hundreds, indicating that the membership at large attaches perhaps 10 times the importance to the office of President that it attaches to the other offices. That is not right. One reason that the presidential nominee receives so many more votes than the other nominees is there is more or less of a concentration upon the one or two names for president, whereas the vote for the other officers is so scattered that each officer receives only a very small one. Our old system was established upon a basis that fundamentally was right. For years we have been going along on the theory that the Board of Directors was a Nominating Committee. I have been a member of almost every Constitutional Revision Committee, except the first one and that has been the theory that has pervaded all their deliberations. With only minor modifications it has stood through the history of the Institute. The early framers of the Constitution, and those who later modified the Constitution, have felt that the Board of Directors represented the membership, and since it represented the membership it was proper that it should be a Nominating Committee. There have been several peculiar controversies, upsets and disputes in the past history of the Board as a Nominating Committee, but I do not think they have been different from the same kind that would have occurred in a separate Nominating Committee.

In respect to territorial or geographical representation, I do not see why the Institute does not already have it, and as I analyze the scheme of nominating officers by one delegate for each 75 members, it will give less than the present territorial representation for unless a member can get 74 others to join with him he will not be represented at all. Every member of the Institute at present, wherever he may be, has the right to cast a nominating vote. He would not have it with the kind of territorial representation proposed.

When the members of the Institute talk about territorial representation, whether they mean the kind of representation that is the senatorial representation in the U. S. Senate, or whether they mean the representation as found in the House of Representatives, is not clear. If they mean Senatorial representation, then we now do not have it. I am not certain it would not be a good thing because the representation would not be proportional to the membership, but nobody in any of the discussions I have yet heard has made it clear that that is what he means when he talks about territorial representation. To discuss the other kind of territorial representation, there is complaint about the system now by which each member has a nominating vote. I do not see how that complaint would be any different if, instead of each member having a nominating vote, every 75 members pooled their nominating vote into one representative and let him vote. The territorial distribution of the nominating vote would be something like what it is at present only its amount would be less. In reducing the amount of the vote we are not changing its principle. At present the man in Oshkosh has a right to vote, but if we adopted the new scheme of voting through delegates, the man in Oshkosh would lose his vote unless he went out and got hold of a man in Kalamazoo, or 74 others, and got them to join with him in having a representative to cast a vote. Only 20 per cent of the Institute membership casts the nominating vote now. Less than 20 per cent would then be represented. Some people say—Yes, but the interest of the man in Oshkosh, would be enhanced, if he felt that by joining with 74 others in the election of a delegate he might have a choice in the election of a counsellor at headquarters. I think as it stands at present, that the delegate, and the ballots electing the delegate, and the delegate coming to headquarters, and all that, would be only additional machinery placed between the member in Oshkosh and the counting of the vote in New York.

The question is separated entirely from that of a majority and a minority nominee. The majority and minority nominee is what affects electioneering; what has been heretofore called territorial division of the vote, affects I do not know exactly what, unless there would be more of an interest in the Institute if the members registered their votes through a delegate.

Under the old system the Board of Directors operated as a Nominating Committee, and only one name was sent out for each office. The candidate named by the Board of Directors was invariably elected. Putting two nominees on the ballot came up some years ago, and then the provision I heard Mr. Thomas very accurately describe was introduced. There is the grossest misunderstanding about it. The idea was that there might be some feeling on the part of the membership, under circumstances which I should hesitate to mention, because they probably never could occur, that some candidate might get the nominating vote because of bias in the Board of Directors who really was not the preferred candidate of the Institute at large. While in general the Institute was ready to trust the Directors as a Nominating Committee, there was a feeling that if any two members, even of the Board, did not think that the Board's nominee was the proper nominee, they might call for a second nominee to be added to the ticket. That is the way the provision of a second nominee came in. That provision has been called into action on two occasions. On one occasion the second nominee was the successful candidate, and on the other occasion the second nominee was not. Because of certain ambiguities in the Constitution, as to the designation of the names of the nominees in both of these cases, it was impossible to tell from the Directors ticket who was the preferred choice of the Board acting as a Nominating Committee and who was the minority nominee. This was the case this year and the membership at large had nothing to guide them as to what might be called the Directors' choice. In my opinion, this was out of harmony with the intent of the Constitution. I believe that the Board of Directors ought to be reconstituted a Nominating Committee, and given the discretion of a nominating committee, or the mandate of the membership, ought to be made clear that it is not to exercise its discretion but simply to send out to the membership the nominations that are the result of the nominating ballots. There is certainly need for some changes, but which direction they shall take, it is for the Institute members to say.

And now, I know it will give you all great pleasure for me to announce that the Chairman of the Sections Committee, who has so ably, so intelligently, and so loyally developed the interests of the Sections for the past two years, has consented to accept the Chairmanship of the Sections Committee for the term of the administration about to commence. I feel that in appointing Mr. Lincoln to the Chairmanship I am carrying out exactly the policy of strengthening the Sections, and giving them an increased voice in the affairs of the Institute, and of contributing to what I regard as one of the strongest and healthiest and best developments of the Institute that I see going on at the present time.

George A. Hoadley: This body expires after this Convention, as far as individual members are concerned. It does not expire, however, as far as the delegates from the Sections are concerned. It seems to me if we go back to our Sections and undertake to make a definite report of the work done by this meeting of Section Delegates, that it would be very well, indeed, if we could have a copy of the stenographer's notes that have been taken this evening to present to the other members of our

Section. That would give us a basis for action, and enable us to place before our Sections in an intelligent and distinct way the work accomplished by this Committee.

Secretary Pope: That will be done.

Gano Dunn: If Mr. Hoadley's suggestion is carried out, I should like to say a word further in regard to an alternative scheme of nomination, which it might be well to present to the membership. One of the difficulties of the present system is that nobody knows in advance who is a candidate.

There is no doubt that a system of nomination by delegates or what has has been called territorial nomination would require ballots to be sent out from headquarters for each Section, and that would throw upon the Secretary's office at New York an enormous amount of extra work, so much that I am confident it would require an additional force to take care of it, and it would also mean that, beginning with the member who elects the delegate, and the delegate who comes and elects the nominee, and the nominee whose name goes out to the membership, and the membership who votes for the nominee, we would be practically going through a continuous process of selection of officers all the year round. That considerable amount of machinery can be avoided, if a scheme which Mr. Hutchinson, our Assistant Secretary, suggests is found practicable, it is nearly the same as we are now following, and I believe will involve no change in the Constitution but only a new by-law. It is a constructive modification of our present method. This method has stood the test of time and been generally accepted by our membership of which a large part does not take the same interest in elections that you do and would find it hard to learn new and complicated methods of voting. Mr. Hutchinson's plan in effect is nomination by petition and nominees will have an official standing. A member from Oshkosh, not knowing whom to nominate, will receive a list of official nominees from the Secretary's office. The Secretary might go so far as to send a photograph of each nominee (humor) to show what kind of a man he is. It is even proposed that the name of each official nominee shall go out accompanied by a short biographical sketch, which should be prepared by five other members, saving the nominee the embarrassment of doing it. This probably is a feature which it would not be well to try at first but which could be added later by a subsequent by-law if experience prompted it. Mr. Hutchinson's plan of nominations is as follows, which I quote from a description of it he has prepared.

NOMINATIONS

The present plan of nominating and electing officers of the Institute is, briefly, as follows:

Nomination blanks are mailed to the membership early in February. The names of the candidates selected are inserted upon these blanks which are then returned to Institute headquarters. The Committee of Tellers then tabulates these nominations and reports to the Board of Directors, which prepares the "Directors' Nominees" ticket as required by the Constitution. A ballot is then prepared and is mailed to the membership early in April; this ballot contains in addition to the "Directors' Nominees" names of all candidates who receive at least three per cent of the total nomination vote. When these ballots are returned the Committee of Tellers canvasses them and reports at the Annual Meeting in May.

The principal objections to the present practice relate not to the actual election, but to the method of making nominations. Some of the objections are as follows:

1. There is no official way by which a group of members who desire to recommend a certain candidate for election can make their wishes known to the entire membership.

2. The majority of members have no means of knowing whether the men who come to their minds as suitable candidates are willing to accept election.

3. The scattering vote is increasing each year. For example, in February, 1911, 225 different members received one or more primary or nomination votes for Vice-President and only seven of these received three per cent, which is the percentage necessary under the Constitution to render a member eligible for election. There were 581 different members who received one or more votes for the office of Manager; only thirteen of these received three per cent. In all probability the majority of these members were not aware that they were being voted for.

4. At present the only way for a group of members to suggest a candidate to the membership is by means of circular letters.

5. In addition to the well known objections to the use of circular letters, there are numerous complaints received at Institute headquarters from members in foreign countries to the effect that they receive each year unofficial campaign literature upon which they have to pay excess postage.

The above facts clearly indicate the need of a simple official method whereby any group of, say 50, members or associates, may suggest to the entire membership the election of any member to any specified office.

An attempt to meet the situation was made a few years ago by the adoption of a new By-Law (See Section 18) requiring that a list shall be published in the January and February PROCEEDINGS each year containing the names of all persons who received three per cent in the primary of the preceding year, and also the names of all directors, and of ex-Vice-Presidents and ex-Managers, who have held office during the preceding five years. This plan does not meet the situation, however, as it does not provide for new candidates. It has also been severely criticized as tending to favor the perpetuation in office of men who have already been elected.

Any radical change in the method of nomination and election will, of course, involve the adoption of an amendment to the Constitution, but the following simple method of making nominations by petition has been devised so that it can be used in accordance with the present Constitution and merely requires the adoption of a new by-law in place of Section 18 of the present by-laws. The suggested by-law is as follows:

SECTION 18. In addition to the names of the incumbents of office, the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May" provided for in Article VI, Section 30, of the Constitution, the names, as Candidates for Nomination, of such Members and Associates of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty Members or Associates, received by the Secretary of the Institute in writing by January twenty fifth of each year.

> The names of such Candidates for Nomination shall be grouped alphabetically under the name of the office for which each is proposed and this by-law shall be reprinted prominently in the January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to.

If this by-law is adopted as a substitute for the present Section 18, all the names proposed by petition may be printed upon one sheet of the regular nomination form but the sheet upon which members write their nominations may be blank as at present, so that any member may, if he desires, refrain from nominating any of the candidates proposed by petition and may nominate any other members of the Institute.

The plan outlined here will if adopted not only eliminate the objections to the present method, but will also bring about the very desirable result of increasing to a considerable extent the number of votes cast in the primaries. During the past five years it is seldom that more than 20 per cent of the membership have sent in their nomination forms, consequently members who receive a comparatively small vote are frequently placed upon the directors' ticket and subsequently elected, whereas it is of course desirable that all candidates elected shall have been the expressed choice of a much larger percentage of the membership. The principal reason for this is that many members do not know who the candidates are. The vote in the actual election for which a printed ballot is issued, containing the names of the candidates has averaged about twice as much as the nomination vote.

This would certainly require much less clerical work in the central office, of the Institute, than the so called territorial scheme. Although electrical engineers are not great respecters of tradition, yet they do respect it, and Mr. Hutchinson's plan would have a great deal to recommend it to the vast body of the membership. In view of Mr. Hoadley's suggestion that the discussion of this meeting be sent out to the members, I felt it was due that this alternative scheme should be presented here, so that it might be duly considered.

If it should be adopted members in any particular locality can concentrate upon a nominee and practically accomplish territorial representation which in the past has been prevented by the scattering of the vote although there were only four managers to be elected this year the vote was distributed among 581 candidates, the most popular of whom received only 4.8 per cent of the vote of the membership and many of the candidates received nearly the same vote which warranted the Board of Directors in using its discretion. Advance nomination by petition will tend to concentrate the nominating vote upon a few candidates and thereby render the will of the membership clearer especially where a particular group of members concentrate their vote on a particular candidate.

P. H. Thomas: If this is printed, it should go to all of the members, or be accessible to the members of the Institute in some form.

The meeting then adjourned.

PROCEEDINGS

of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

SECTION II

Papers, Discussions and Reports

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A paper to be presented at the 268th meeting of the American Institute of Electrical Engineers, New York, February 9, 1912.

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(Subject to final revision for the Transactions.)

A METHOD OF STUDYING POWER COSTS WITH REFERENCE TO THE LOAD CURVE AND OVERLOAD ECONOMIES

BY GEORGE I. RHODES

A great many curves have been presented before the Institute showing the relation between load factor and the cost of power. Some of them were based on very simple relationships between the elements entering into the total cost, and others have been of a purely empirical nature based on actual results. The interrelation of the various items of power cost is necessarily very complicated and dependent to a large measure on the skill and judgment of the engineer in charge. Few plants have been operated at any considerable range of load factor under the same operating engineer. It has been the privilege of the author to work up many of the curves presented to this Institute and he has been led to the belief that a more extended study of the subject is necessary in order to find the means of properly comparing the costs of power in different plants operating under different management, load conditions, coal costs, labor costs, and other circumstances.

By far the largest and most important item entering into the cost of power is that of fuel, which is determined by the cost of coal and the operating economies of the prime movers and the boilers. The type of load carried has a large influence on the thermal efficiency. A fluctuating load requires more coal than an equal steady load. A load extending throughout the day with large peaks morning and night, requires more fuel than a steady and uniform load lasting for a part of the day.

In order to deduce operating economies from test results, taking into account all of the items producing variation, a certain classification of losses, etc., is desirable.

RELATION OF LOAD FACTOR TO OPERATING POWER COSTS

In electrical apparatus the relation between input and output of energy is made up of three items:

A. An input proportional to the output, the ratio between which depends on the theoretical maximum efficiency of transformation. In electrical apparatus this efficiency is unity because there are no losses which are theoretically unavoidable.

B. An input sufficient to supply all the no load losses, namely, excitation, core loss, friction, windage, etc.

C. An input proportional to the square of the load which supplies the various load losses, resistance, magnetic, etc.

In thermodynamic apparatus, however, this simple relationship between the input and the output has not been demonstrated as completely as is the case in electrical energy transforming devices. It is probable that the closeness of such a relationship is by no means as exact. However, the general formation of the curves obtained from tests leads one to expect that such a corelation of the losses and the load does exist with a greater or less degree of approximation. It is not as easy to determine thermodynamic as electrical losses.

However, the losses in heat engines may be classified as follows, similarly to the electrical classification:

A. An input proportional to the load, the ratio depending on the maximum theoretical efficiency.

In steam boilers this efficiency may closely approach unity, the only unavoidable source of loss being in the fact that the flue gas temperature must be at least equal to that of the steam.

In prime movers the maximum ideal efficiency is that of the Carnot cycle determined by the steam temperature and the vacuum. This efficiency can never be equalled in practice, but the losses over and above those necessary for this cycle can be taken care of as load losses.

B. An input sufficient to cover all radiation, friction, windage and other no-load losses.

These losses are sensibly constant at all loads and may thus be measured as no-load losses in either boiler or prime mover. The variation from constancy may be taken care of by the load losses.

C. An input dependent upon the losses caused by the load.

In a boiler and furnace the load losses are practically all in the flue gases. As the load is increased it is necessary to pass more air through the fire, thus increasing the volume of the flue gases in proportion approximately equal to the increase in the load. The temperature of the flue gases is also increased above that of the steam in a similar proportion. It is thus evident that the volume and the temperature of gases each being increased approximately in direct proportion to the load, the losses thus occasioned are closely proportional to the square of the load. There are other load losses but they are relatively small.

In a prime mover having a perfect cycle there is a certain amount of heat rejected to the condenser. It is probable that at no load, a slight additional load will be developed at an efficiency closely approximating the ideal. With increase in load the cycle departs more and more from this ideal, the increased loss per unit of input being somewhat in proportion to the load. Since there is an increased heat input proportional to the load, the total load losses will increase as the square of the load.

There is no doubt but that this load, squared, relationship is far less exact in thermodynamic than in electrical apparatus. Tests of heat apparatus are by no means as accurate or as consistent as those of electrical machines, because the conditions under which they are made are far less constant and controllable. Under normal operation these conditions are still more variable. It would thus appear that the assumption of the classification of input to steam apparatus on the basis outlined is warranted for purposes of studying the probable relationship of power cost and load.

Thus if

l = the output of the apparatus
R = " rating of the apparatus
A = " input proportional to the load
B = " input independent of the load per unit rating
C = " input proportional to the square of the load per unit rating
h = " total input

$$h = Al + B\,R + C\,R\,\frac{l^2}{R^2} = Al + B\,R + C\,\frac{l^2}{R}$$

If a subscript P indicates references to the prime mover equipment, and a subscript B indicates reference to the boiler equipment, the input to the engine room of a single unit is

$$h_P = A_P\, l_P + B_P\, R_P + C_P\, \frac{l^2_P}{R_P} \tag{1}$$

At full load $h_P = R_P\,(A_P + B_P + C_P) = R_P\, H_P$
If the boiler room rating $= r\, R_P\, H_P$

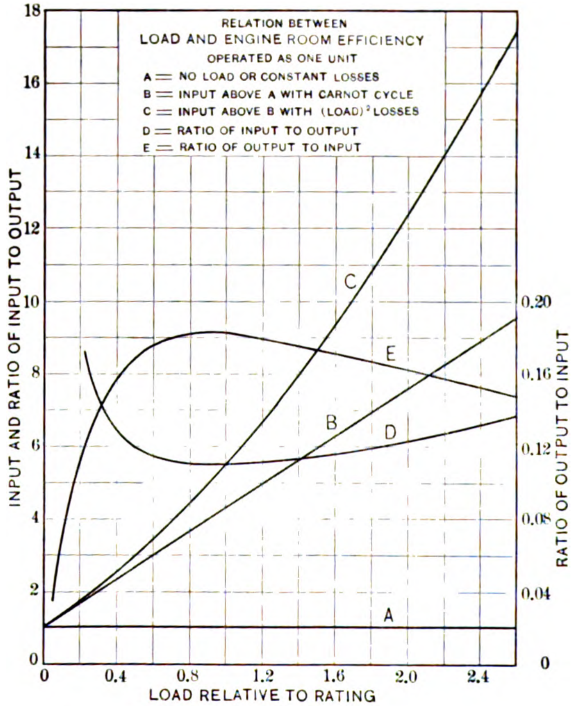


FIG. 1

The input to the boiler room of a single unit is

$$h_B = A_B\, l_3 + B_B\, R_P + C_B\, \frac{l^2_B}{R_B} = A_B\, h_P + B_B r\, R_P\, H_P + C_B\, \frac{h^2_P}{r R_P\, H_P} \tag{2}$$

The constants of these equations may be determined from a study of the net heat energy required by the engine room and by the boiler room of any plant.

As an illustration of the meaning of these equations Figs. 1 and 2 will suffice. Fig. 1, curve *C*, is plotted for the case where $A_P=3.30$, $B_P=1.00$, $C_P=1.20$. Curves are also shown which give the usual method of expressing the efficiency of the unit, in input per unit output (*D*) and its reciprocal (*E*). It will be noted that there is nothing unusual about these curves; in fact they are quite typical of what may be expected for a turbine room. There is a marked rise in heat consumption per unit output at light loads due to unavoidable no-load losses in the unit itself and in its auxiliaries. There is a similar but much less rapid increase at overloads due to the load losses and the inability of the condenser to maintain its full vacuum. Fig. 2 is plotted for the case where $A_B=1.09$, $B_B=0.07$, $C_B=0.29$. Here again the curves well represent the condition in a boiler room as normally operated.

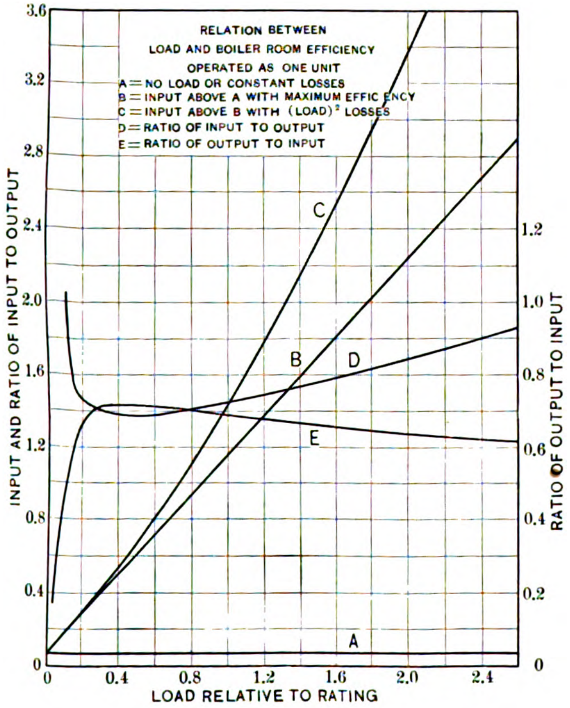


FIG. 2

To determine the combined efficiency of the plant it is necessary to develop equation (2) so that its only variable is that of the load on the prime movers. This developed equation is of the form

$$h_B = K_0 R_P + K_1 l_P + K_2 \frac{l_P^2}{R_P} + K_3 \frac{l_P^3}{R_P^2} + K_4 \frac{l_P^4}{R_P^3} \qquad (3)$$

With the engine room and boiler room of the constants given above, and the additional constant $r = l$, or the rating of the

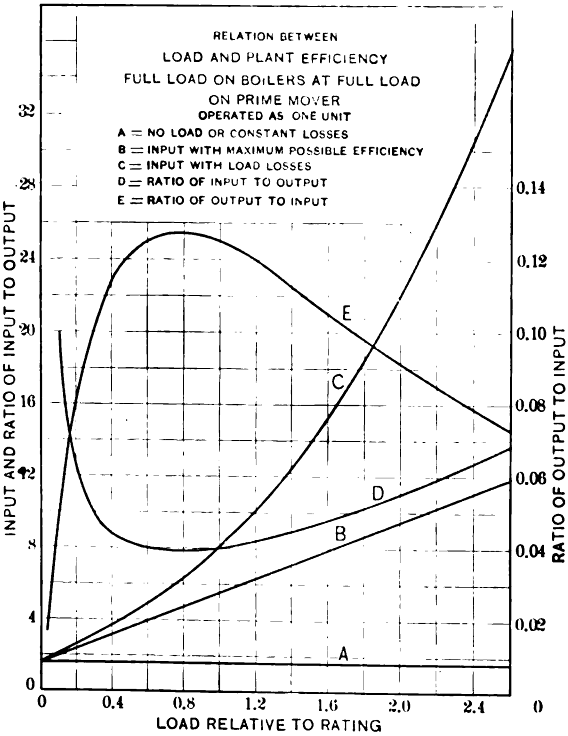


FIG. 3

boiler room such that it will deliver its rated output for full load on the engine room, the combined efficiencies are as shown on Fig. 3.

The equation becomes

$$h_B = 1.55\, R_P + 3.95\, l_P + 2.01 \frac{l_P^2}{R_P} + 0.42 \frac{l_P^3}{R_P^2} + 0.08 \frac{l_P^4}{R_P^3}$$

Here as before the curves are quite normal.

In any actual plant, however, the operation is not as one unit. There are about five units in a well designed plant and no more are operated than are necessary to carry the load economically. Fig. 4 shows the relation between load and efficiency of a turbine room of five units, each having the characteristics given above. It will be noted that there is a succession of curves each corresponding to the number of units running. It is probable that at any time when less than the full equipment is running certain additional steam is being used for purposes of warming up units or turning them over for adjustment. A straight line extending from a point corresponding to the input of one unit at no load to another corresponding to all units at full load will probably give a close approximation to the actual amount of energy used. For this particular case the equation is

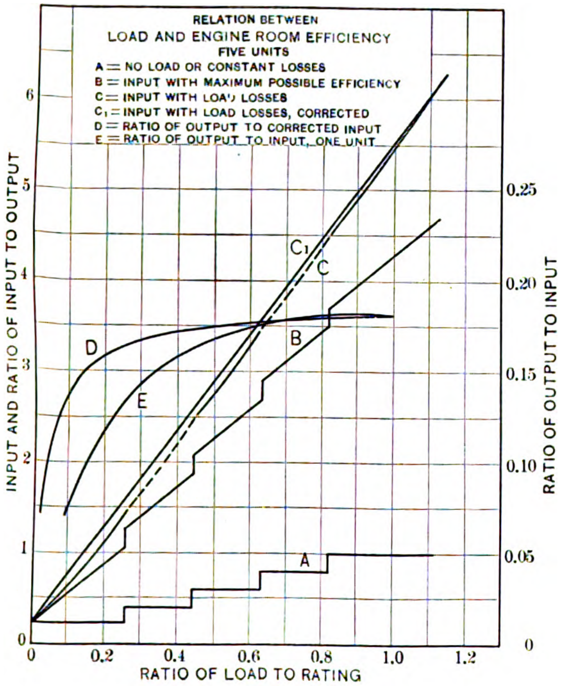


FIG. 4

$$h_p = 0.2\,R_p + 5.3\,l_p$$

The general equation is

$$h_P = \frac{B_P R_P}{N} + \left[H_P - \frac{B_P}{N} \right] l_P$$

It will be noted from the curves *D* and *E*, Fig. 4, that there is a very material saving due to having several units, each carrying its proper load.

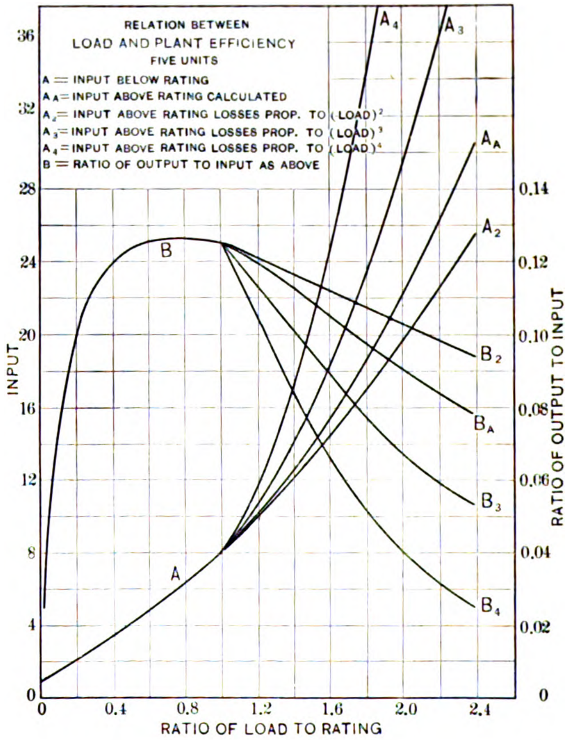


FIG. 5

In the boiler room the difficulty of starting up cold boilers practically necessitates keeping them under pressure and with banked fires in the furnace at times of light load. Accordingly the efficiency of the boiler room is not materially affected by the number of units and the equation (2) may be considered as applying in all cases.

Substituting values from equation (4) into equation (2) will give the relation between load on the plant and boiler room input for a plant with several units.

For the case used above the equation becomes

$$h_B = 0.62\, R_P + 5.90\, l_P + 1.48\, \frac{l_P^2}{R}$$

This relationship is shown by curve *A* Fig. 5. When the plant is overloaded the relationship is the same as for a plant of a single unit and is shown in curve A_A. The other curves represent the input when the losses at overload are proportional to the square, cube and fourth power of the load.

In any plant the load varies both momentarily, due to fluctuations, and hourly, accordingly to a more or less well defined load curve. On account of the curved line relationship between rate of input and load, the total input over any period will differ from the input corresponding to the average load over that period.

If H = the total energy supplied

$$H = \int_0^T h_B\, dt = K_0\, R_0\, T + K_1 \int_0^T l_P\, dt +$$

$$\frac{K_2}{R_P} \int_0^T l_P^2\, d\,t + \frac{K_3}{R_P^2} \int_0^T l_P^3\, dt + \frac{K_4}{R_P^3} \int l^4\, dt$$

$\int_0^T l\, dt$ = total output = average load into time.

$= L_A{}^T$ where L_A = average load.

$\int_0^T l^2\, dt$ = the time integral of the square of the load.

$= L_{A2}\, T$ where L_{A2} = mean square of the load.

$\int_0^T l^3\, dt$ $= L_{A3}\, T$ where L_{A3} = mean cube of the load.

$\int_0^T l^4\, dt$ $= L_{A4}\, T$ where L_{A4} = mean fourth power of the load.

Thus

$$H = K_0\, R_P\, T + K_1\, L_A\, T + \frac{K_2\, L_{A2}\, T}{R_P} + \frac{K_3\, L_{A3}\, T}{R_P^2} + \frac{K_4\, L_{A4}\, T}{R_P^3}$$

If all units are in kilowatts, kilowatt-hours and hours, H is in kilowatt-hours.

In order properly to appreciate the meaning of this equation it is necessary to apply it to a particular case. For a normal load curve having an average load during the year of about 40 per cent of the maximum hour the mean square load $= 16 (1.06)^4$ per cent.

For a 40 per cent steady load the heat input is

$$h_B = [0.63 + (5.90 \times 0.4) + (1.49 \times 0.16)]\ R_P = 3.23\ R_P$$

For a 40 per cent load curve as above

$$h_B = [0.63 + (5.90 \times 0.4) + (1.49 \times 0.16 \times (1.06)^4)]\ R_P = 3.30\ R_P$$

The small difference observed here is due to the fact that there is but little curvature for loads below rating. With greater curvature the difference would be greater.

In all of the above relationships input and output are expressed in the same unit, namely, kilowatts or kilowatt-hours. Coal is purchased by the ton in the great majority of plants, but the practice of purchase on the B.t.u. basis is becoming more and more prevalent. In the vicinity of New York, heat in the form of coal costs approximately 9,750,000 B.t.u. per dollar, which translated into kilowatt-hours is 0.350 mills per kw-hr. in the coal. Expressing coal costs in this manner allows the transformation of the above equations to dollars and cents.

The division of the other items into classes, depending on different functions of the load, is far more difficult than that of coal. Here the skill and judgment of the operating engineer is the most important factor. However, it is certain that were the plant to be maintained at all times ready for instant service and yet deliver no energy, there would be a very considerable cost for labor and supplies to take care of the no-load losses, and of the maintenance for instant service. This cost corresponds to the no-load losses in the apparatus. It is similarly certain that the delivery of energy requires additional labor and supplies in an amount measured by the energy delivered. If the plant is overloaded there are additional costs occasioned by the more careful supervision required by overloaded apparatus, and the maintenance costs, which in all apparatus increase at a rate faster than that of the coal.

The determination of the proportions between these classes of costs is by no means a simple matter. Experience alone can give such a determination, but the author believes that a classification based on the following outline will give a fair working basis for comparison.

LOADS BELOW RATING

Coal. Proportioned as in equations (2) and (4).

Lubrication, supplies, water. Proportioned as per steam for one unit (1).

Coal and ash handling maintenance. Independent of load and rating.

Coal and ash handling operation. Proportioned as per coal for one unit (2) and (1).

Boiler room maintenance. Ditto.
Boiler room operation. Ditto.
Engine room maintenance. Proportioned as per steam for one unit (1).
Engine room operation. Ditto.
Electrical maintenance. Independent of load or rating.
Electrical operation. Ditto.

The following table is deduced from data given in "Notes on the Cost of Power" H. G. Stott, TRANSACTIONS A.I.E.E., Vol. XXVII, p. 283. The classification is made to correspond with that outlined above and the constants for the equations are given in mills per hour per kilowatt rating. In the division into classes it was assumed that the load factor was 50 per cent and that the shape of the curve was such that the mean square of the load was equal to the square of the mean load multiplied by $(1.05)^4$, the mean cube equal to the cube of the mean multiplied by $(1.05)^6$, etc. The usual types of load curves have similar constants or characteristics.

OPERATION & MAINTENANCE COST OF POWER
STEAM TURBINE PLANT. LOADS BELOW RATING
MILLS PER HOUR PER KW. RATING

Item	From Table Mills per Kw.-hr. 50 per cent. L. F.	Constants in Equations				
		K_0	K_1	K_2	K_3	K_4
Coal	.....	0.217	2.065	0.521	.....	.....
Lubrication Water Supplies	0.078	0.013	0.043	0.016	.....	.....
Coal & Ash. Hand. Maint	0.030	0.015	.....	.....	.....	.....
" " " " Oper	0.170	0.031	0.080	0.040	0.009	0.001
Boiler Room Maint	0.238	0.044	0.111	0.057	0.012	0.002
" " Oper	0.371	0.068	0.174	0.089	0.018	0.003
Turbine Room Maint	0.028	0.005	0.016	0.006	.....	.....
" " Oper	0.075	0.013	0.041	0.015	.....	.....
Electrical Maint	0.062	0.031	.....	.....	.....	.....
" Oper	0.139	0.070	.....	.....	.....	.....
Total, except coal	1.191	0.290	0.465	0.223	0.039	0.006
" with "	.....	0.507	2.530	0.744	0.039	0.006
FOR LOADS ABOVE RATING						
Coal	.....	0.543	1.381	0.704	0.147	0.028
Total with coal	.....	0.833	1.846	0.927	0.186	0.034

Fig. 6 shows graphically the relation between cost and load factor under ordinary conditions of load variation as well as for steady load equal to the average. It will be noted that the increase in cost caused by the varying load is not very large, being only about 2 per cent. at 40 per cent. load factor. In a plant having greater load losses this difference would be greater.

EFFECT OF POOR ECONOMY AT OVER-LOADS ON THE COST OF POWER

In a plant whose rating is equal to the maximum hour the operation and maintenance costs, exclusive of coal, are, in mills per hour (from above table)

$$0.290\,R+0.465\,L_A+0.223\,\frac{L_{A2}}{R}+0.039\,\frac{L_{A3}}{R^2}+0.006\,\frac{L_{A4}}{R^3}$$

It is probable that the items of coal and ash handling maintenance and electrical maintenance and operation would be unaffected by the size of the plant, provided it is to carry the same load. In all other items the effect of reduction in the size of the plant to carry any given load is taken care of by the increased steam and coal consumption.

Thus M = the maximum hour load.

The cost of operation and maintenance, exclusive of coal, per hour per kilowatt maximum hour becomes

$$0.116+0.174\,\frac{R}{M}+0.465\,L_A+0.223\,\frac{ML_{A2}}{R}+$$

$$0.039\,\frac{M^2L_{A3}}{R^2}+0.006\,\frac{M^3L_{A4}}{R^3}$$

The cost of coal is

$$0.217\,\frac{R}{M}+2.065\,L_A+0.521\,\frac{M\,L_{A2}}{R}\qquad\text{when underloaded}$$

and

$$0.543\,\frac{R}{M}+1.381\,L_A+0.704\,\frac{ML_{A2}}{R}+0.147\,\frac{M^2L_{A3}}{R^2}+0.028\,\frac{M^3L_{A4}}{R^3}$$

when overloaded.

In any plant it would be possible to increase the maximum hour capacity by an expenditure per kilowatt much less than the original cost of the plant. Conversely, if a plant is designed with smaller normal rating but with the same maximum hour capacity secured even by wasteful use of steam or fuel the cost per kilowatt maximum hour will be less than that of the first plant, but not in the same proportion as their relative ratings. Thus let it be assumed that a plant costs $80 per kilowatt of normal rating and that the overload capacity can be increased to any reasonable extent by a further expenditure of $40 per kilowatt. It would thus appear that the cost of such a plant per kilowatt maximum hour capacity would be

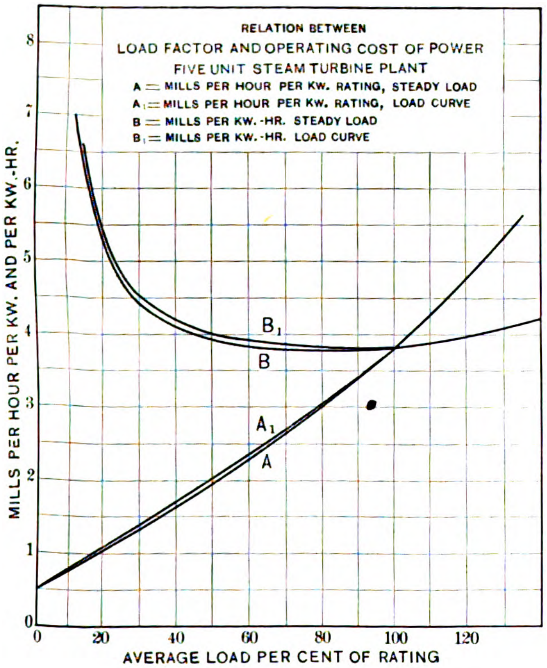


FIG. 6

$$\$40+\$40\,\frac{R}{M}$$

If fixed charges are at 12 per cent. per annum they will be at the rate of

$$0.548+0.548\,\frac{R}{M}$$

mills per hour per maximum hour kilowatt.

If a study is made of any given load curve it is possible from the foregoing equations to determine the effect on the total cost of power, of reducing the nominal rating of the plant but with the same maximum hour capacity. If the rate of increase of load losses at overloads is given varying magnitudes an idea may be gained of the extent to which poor economy at overloads may be carried and still reduce the total cost of power. To do this the various items of load losses may be combined into one, which may be taken as varying as the square, cube, or even fourth power of the load (See Fig. 5).

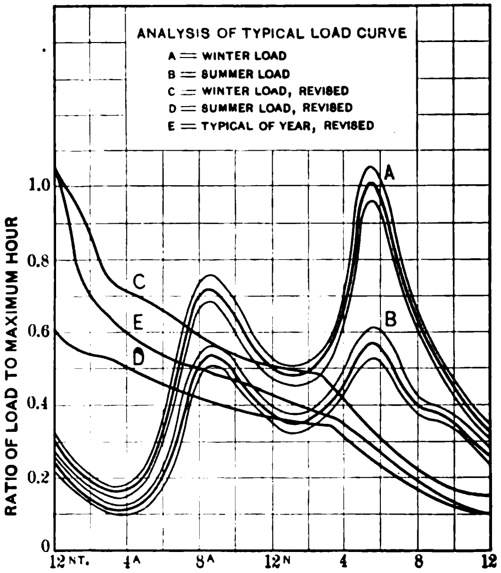


FIG. 7

It is evident that to make such an investigation a very complete analysis of the load needs to be made on the following basis:

A = The hours per year that the load exceeds various amounts.
B = The average load during all these periods.
C = The average square of the load during these periods.
D = The average cube of the load during these periods.
E = The average fourth power of the load during these periods.

Similarly the same information is needed covering the rest of the energy generated, that is, when the load is less than these various amounts taken for comparison.

During the periods when the load exceeds any amount the costs may be determined from the overload equation of the plant whose rating is that amount. During the other periods the underload equation for this same size plant will determine the costs.

Fig. 7 shows what may be considered as a typical city load curve, the heavy lines showing the mean load, and the lighter lines the limits of fluctuation. If the abscissas of these curves are combined as in curves *C* and *D* the curve then represents the hours per day that the load exceeds the value of the ordinate at any point. The curve *E* is the probable curve covering the entire year. It will be noted that such a curve takes into account not only the hourly variations but also the momentary fluctuations.

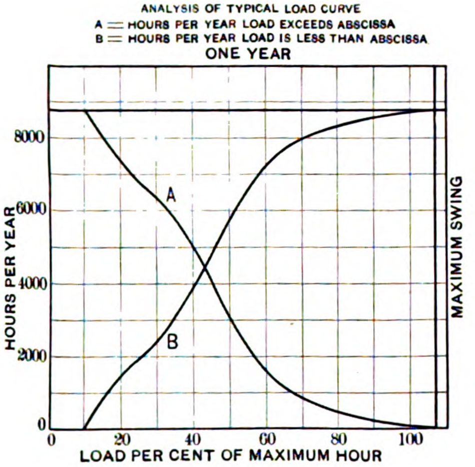


FIG. 8

Fig. 8 shows the hours per year, corresponding to Fig. 7, that the load exceeds or is less than any given amount. Fig. 9 shows the time integrals of the load (kw-hr.), the square of the load, etc., for all loads exceeding various amounts. Fig. 10 gives this same information for the loads below these amounts. There is thus a complete analysis of a typical city load curve, which applied to equations developed above will make possible the determination of the overload capacity corresponding to the minimum total cost of power.

Figs. 2, 11 and 12, show in detail the cost of generating power

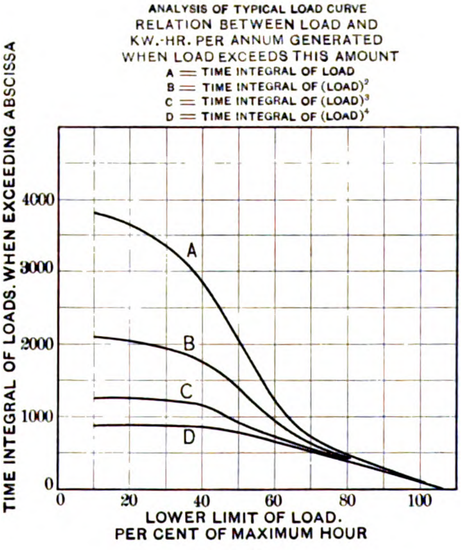

ANALYSIS OF TYPICAL LOAD CURVE
RELATION BETWEEN LOAD AND
KW.-HR. PER ANNUM GENERATED
WHEN LOAD EXCEEDS THIS AMOUNT
A = TIME INTEGRAL OF LOAD
B = TIME INTEGRAL OF (LOAD)²
C = TIME INTEGRAL OF (LOAD)³
D = TIME INTEGRAL OF (LOAD)⁴
TIME INTEGRAL OF LOADS. WHEN EXCEEDING ABSCISSA
4000
3000
2000
1000
0
A
B
C
D
0
20
40
60
80
100
LOWER LIMIT OF LOAD.
PER CENT OF MAXIMUM HOUR

FIG. 9

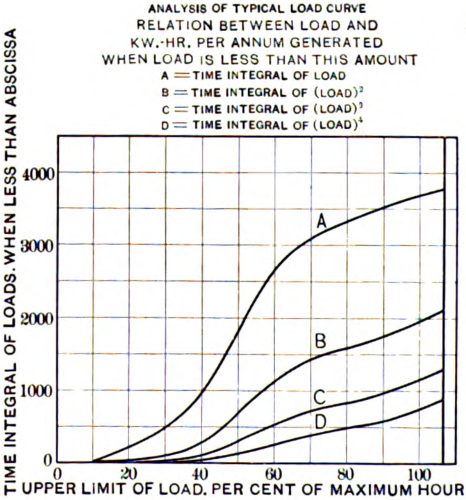

ANALYSIS OF TYPICAL LOAD CURVE
RELATION BETWEEN LOAD AND
KW.-HR. PER ANNUM GENERATED
WHEN LOAD IS LESS THAN THIS AMOUNT
A = TIME INTEGRAL OF LOAD
B = TIME INTEGRAL OF (LOAD)²
C = TIME INTEGRAL OF (LOAD)³
D = TIME INTEGRAL OF (LOAD)⁴
TIME INTEGRAL OF LOADS. WHEN LESS THAN ABSCISSA
4000
3000
2000
1000
0
A
B
C
D
0
20
40
60
80
100
UPPER LIMIT OF LOAD. PER CENT OF MAXIMUM HOUR

FIG. 10

as per the load curve, operating and fixed costs given above. The solid lines represent the costs when overloads are secured without the use of inefficient means. However, to determine the effect of extra poor economy at overloads the dotted curves were compiled in which the costs of load losses etc., at overload are proportioned to the square, the cube, and the fourth power of the load.

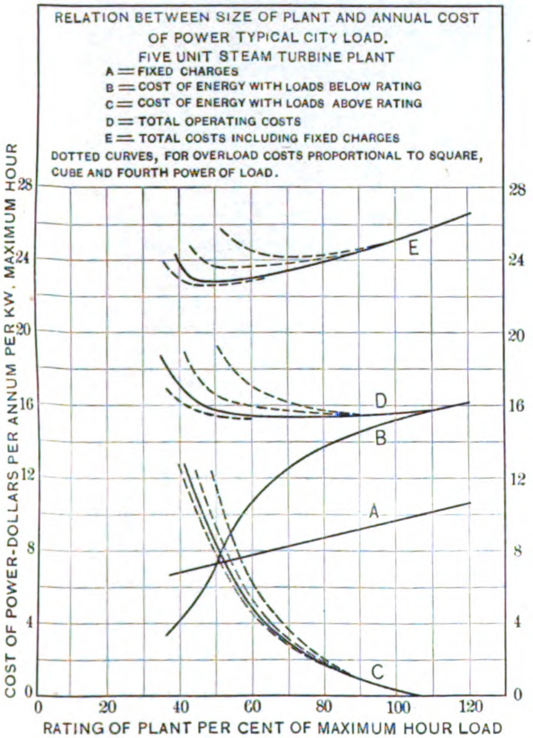


FIG. 11

In all of the comparisons for these curves the overload costs have included not only that of fuel, but also that of labor and supplies. It is thus apparent that that portion of the cost of running the plant during times of overload has a tendency to be excessive for it is by no means certain that the labor costs for operation and maintenance are increased at overloads in the same degree as that of coal. The curves in Figs. 10 to 12 are thus conservative. A glance at Figs. 13 and 14 will show the

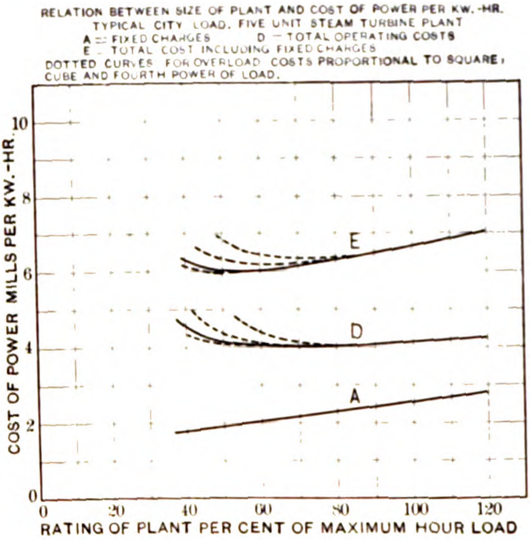

RELATION BETWEEN SIZE OF PLANT AND COST OF POWER PER KW.-HR.
TYPICAL CITY LOAD. FIVE UNIT STEAM TURBINE PLANT
A = FIXED CHARGES D = TOTAL OPERATING COSTS
E = TOTAL COST INCLUDING FIXED CHARGES
DOTTED CURVES FOR OVERLOAD COSTS PROPORTIONAL TO SQUARE, CUBE AND FOURTH POWER OF LOAD.
COST OF POWER MILLS PER KW.-HR.
0
2
4
6
8
10
E
D
A
0
20
40
60
80
100
120
RATING OF PLANT PER CENT OF MAXIMUM HOUR LOAD

FIG. 12

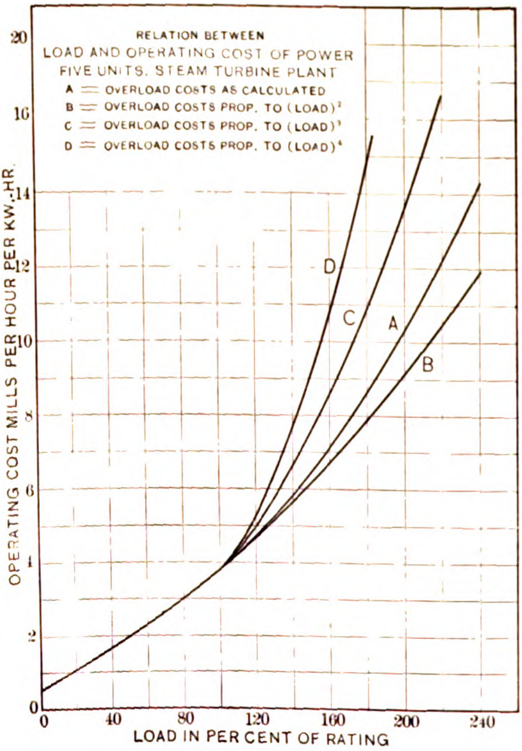

RELATION BETWEEN
LOAD AND OPERATING COST OF POWER
FIVE UNITS, STEAM TURBINE PLANT
A = OVERLOAD COSTS AS CALCULATED
B = OVERLOAD COSTS PROP. TO (LOAD)²
C = OVERLOAD COSTS PROP. TO (LOAD)³
D = OVERLOAD COSTS PROP. TO (LOAD)⁴
OPERATING COST MILLS PER HOUR PER KW.-HR.
0
2
4
6
8
10
12
14
16
20
D
C
A
B
0
40
80
120
160
200
240
LOAD IN PER CENT OF RATING

FIG. 13

enormous increase in power costs allowed in making the determination for Figs. 10 to 12.

In spite of very large costs at overload, it is seen (Figs. 11 and 12) that there is actually a reduction in operating costs with a reduction in rating, due to the fact that the saving in no-load losses more than counterbalances the effect of the cost of overload losses. With fourth power costs, this reduction continues to only about 85 per cent rating but in other cases it continues to even lower ratings. Where the saving in fixed charges is added the resultant costs show reduction for ratings down to 70 per cent even with the worst possible case, while under the probable conditions the improvement continues down to 50 per cent rating. It is quite striking that with a very wide range of poor economy at overload a very material reduction in total costs of power may be secured by running the plant at enormous overloads during the winter peak loads, the limit being only that of available apparatus.

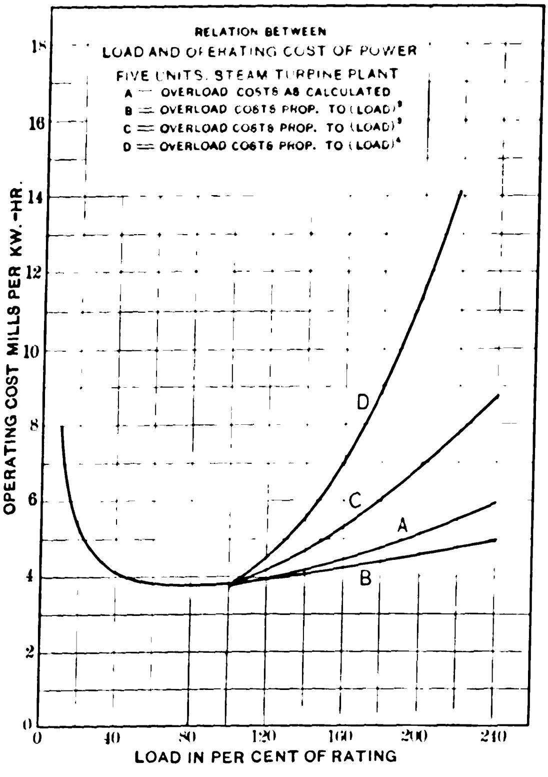


FIG. 14

At 60 per cent plant rating the maximum load on the turbine room is about 170 per cent while that on the boiler room is about 200 per cent. In the turbine room these overloads are not possible at present but there should be no difficulty in securing them if poor economy is allowable.

In order to insure against the possibility of one unit being out of service during the peak load at any time the overload capacity of the prime movers should be sufficient to cover the additional load per unit occasioned by such failure. In the case studied for a five-unit plant rated at 60 per cent of maximum hour, the maximum capacity to cover this insurance should be 210 per cent of normal rating. In the boiler room the large number of units makes the additional capacity unnecessary. On account of the fact that this extra capacity for insurance purposes may never be called upon, the operating cost when it is used is of no importance whatever.

In the boiler room it is possible even now to secure greater overloads than called for, even without material reduction in economy. Some gain in power cost may be made by reducing the boiler equipment, but only about one-half to two-thirds of that obtained by reducing the entire plant.

To sum up the matter, it appears that under ordinary city load conditions, where the maximum loads appear only a few times a year, the power plant should be of such size that it will run at the maximum possible overload during these peaks, with sufficient margin for insurance, and that a large sacrifice in overload economy may be allowed if by so doing this overload capacity can be secured.

DISCUSSION ON "METHODS OF VARYING THE SPEED OF ALTERNATING-CURRENT MOTORS. (MAIER) NEW YORK, DECEMBER 8, 1911. (SEE PROCEEDINGS FOR DECEMBER, 1911.)

(Subject to final revision for the Transactions.)

H. W. Buck: There is a popular idea that alternating-current motors can be used only where constant speed is allowable, and that where variable speed is required it is necessary to convert the alternating current into direct current and obtain in this way the flexible speed variation through direct-current motors.

Recent developments in this country and abroad in variable speed alternating-current motors, which have not as yet been extensively applied commercially, afford means for many industrial purposes of variable speed control almost as flexible as that obtainable with direct-current machinery.

The variable speed alternating-current motor is a very important field for development work and a paper like this of Mr. Maier which points out the direction in which the development is taking place, is of great value.

Mr. Maier's paper is an excellent resume of the art as it stands to-day and should be suggestive and instructive to those interested in this branch of electrical engineering.

R. N. Dickinson: I ask Mr. Buck if the developments he speaks of are in multiphase machines or single-phase machines?

H. W. Buck: In both.

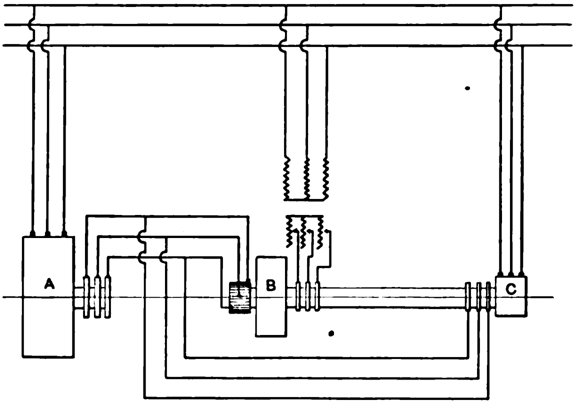
W. N. Smith: I will ask a question which perhaps Mr. Maier or some of the manufacturers represented here can answer. Take the case of a large outfit of motors to drive machine tools in shops such as you have in a locomotive repair shop, or in one of the larger industrial plants. Which of the systems mentioned in the paper this evening have actually been tried on a commercial scale at the present time, and found satisfactory? Possibly some information, showing what has been actually accomplished in practice, would be worth hearing.

G. A. Maier: At the present time in this country there is only one type of adjustable speed motor which is used, that is the multi-speed motor, which is used to a limited extent. In Europe they have used the adjustable speed single- and three-phase commutated motors but I do not think there has been much use made of those motors in this country up to the present time. The slip ring motor is used in some cases where the torque is constant and continuous, such as wheel laths or boring mills doing certain classes of work where the load is always on; the load must be constant and continuous. For general machine tool work, the alternating-current motor has not been used to any considerable extent in this country.

C. J. Fechheimer: An account of a system other than described by the author of this paper for obtaining adjustable speeds appeared in the *Electrotechnische Zeitschrift* of October 19, 1911. This is the system which has been brought out by A. Heyland and R. Ruedenberg. It is somewhat comparable to the Scherbius and Kraemer systems and the accompanying sketch shows the scheme of connections.

The large polyphase induction motor *A* is to have its speed adjusted to suit the requirements. The stator of this motor is connected to the line and its slip rings are connected to the commutator of a machine having an armature similar to that of a synchronous converter. The slip rings of this converter, or more properly, frequency changer, are connected to the secondary of the transformer, the primary of which is connected to the line.

On the same shaft with this machine is a small induction motor *C* with primaries connected to the line and secondary connected in parallel with the slip rings of the large induction motor. The speed is adjusted by changing the number of turns in the secondary of the transformer, which changes the voltage between slip rings of the frequency changer *B*, which in turn alters the pressure between the brushes on the commutator end of this machine. As is well known, a change in voltage between the slip rings of an induction motor will change its speed. The speed of the frequency changer is set by means of the small induction motor *C*.



It is very interesting to note that the frequency changer *B* has no windings on its stator except those which are used to neutralize the unbalanced higher harmonics of armature reaction and thus assist commutation.

Now when we consider whether it is advisable to use a polyphase commutator motor to secure adjustable or variable speed, we must remember that in America it is essential to design apparatus which is practically fool-proof. In other words, after the machine is installed, it is necessary for it to do the work intended for it and not require much attention.

Judging from the great length of time that has been required to successfully design direct current machines and secure satisfactory commutation, we may expect an equal or greater length of time to be able to predict satisfactorily the commutation in alternating-current commutator motors. It is in fact doubtful whether polyphase commutator motors can be designed in large sizes without sparking, so that the question arises: will any variable speed systems which involve the use of alternating-current commutator motors for large outputs be acceptable on the American market?

It has occurred to me that we might use a system which, while costly, would be absolutely certain of results. This system is outlined in Mr. Maier's paper and we suggest a modification of it—one which I have thought of employing a number of times. When there is a direct-current source of supply it consists of an inverted synchronous converter or motor-generator set. The speed is varied by changing the field strength of the converter or direct-current motor. The speed of the induction or synchronous motor changes with the speed of the converter or motor-generator. Or, if the source of supply be alternating, two synchronous converters may be used, one to change from alternating to direct and the other from direct to alternating. By using a split pole converter for the first machine and changing the field excitation of the second, or by having reactance coils in series with the first machine and varying the field strengths of both converters, the frequency may be altered as desired with corresponding changes in the speed of the main induction or synchronous motor.

These systems would be especially applicable to cases to which direct current cannot be directly applied, such as for large capacities and high speeds for which direct current motors cannot be built. We could then use synchronous or induction motors, and have their speeds varied as indicated above.

B. G. Lamme: The question has been asked this evening, to what extent adjustable speed or variable speed alternating-current motors have been used in machine tool drive. Mr. Maier has replied to this question by stating that multi-speed motors without commutators have been used to a limited extent.

I can cite one case where commutator type alternating-current motors have been used for adjustable speed, not in machine tool work, but in print work where print rolls had to be driven at various speeds between zero and full speed. The motors used in this case were somewhat different from any described in the paper of the evening, although based upon the same principles.

In a single phase commutator type motor it is obvious that if the field winding be connected in shunt with the armature, the operation of the motor will be very poor, because the shunt field current, and therefore the field flux, will lag practically 90 deg. behind the armature current, whereas, for good operation the armature current and the field magnetism should be practically in phase. This condition can be obtained by connecting the field winding to a supply circuit which has practically a 90 deg. phase relation to the circuit which supplies the armature. This is illustrated in Fig. 1. With this arrangement the field current, or field flux, is still 90 deg. behind the exciting e.m.f., but as this latter is practically 90 deg. out of phase with the armature e.m.f., the field or exciting flux will thus be practically in phase with the armature current and the machine becomes the equivalent of an ordinary shunt machine. Such a motor can be connected either across a two-phase circuit or can be connected to a three-phase circuit by certain arrangements of the windings which give the equivalent of a two-phase condition.

With this arrangement the speed can be controlled just as with a shunt-wound direct current machine, either by field control or by control of the armature voltage. In the direct-current shunt machine, field control is obtained by insertion of resistance in the field circuit. In this alternating-current motor, field control is obtained by insertion of reactance in the field circuit, instead of resistance. As the field current already lags practically 90 deg. behind its supply e.m.f., the addition of reactance in series does not modify the phase relations materially. Added reactance thus causes weaker fields and increase in speed.

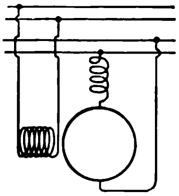


Fig. 1

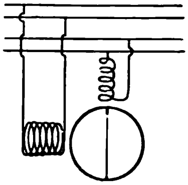


Fig. 2

The speed of such a motor can also be varied by means of resistance in the armature, the same as a direct-current machine, to give variable speed; or can be regulated by means of adjustable voltage supplied to the armature terminals from a transformer with taps. This will give practically constant speed characteristics for any given adjustment. The arrangement thus becomes the equivalent of a direct-current shunt motor with an adjustable supply voltage.

An equivalent arrangement to this was also built and tested, in which the armature was not connected directly across the line but was closed on itself and was supplied with current from a transformer winding on the primary or field core. This arrangement is shown in Fig. 2.

Several motors of the first described type were put into commercial operation. One of these motors was of 20 h.p. normal capacity and another of 30 h.p., both for 25 cycles. Both were controlled by adjustable armature voltage from transformers. The speed was adjustable from practically zero to 1000 rev. per min. The 20-h.p. motor was in operation for about 18 months and was apparently a very satisfactory machine. The 30-h.p. motor was operated for a much shorter period and was not nearly as satisfactory. Later both motors were taken out of service, partly because the system of operation of the plant was modified. The equipments were expensive, due partly to the cost of the regulating transformer, but they could be operated successfully in the hands of careful men. However, the apparatus was rather delicate in its characteristics compared with direct-current machines with equivalent characteristics.

In going over this paper hurriedly, I find several points which are open to discussion. On the last two pages of the paper where reference is made to the Kraemer and Scherbius systems, certain features of these systems are not brought out fully. Both of these are forms of the so-called cascade connection in which the secondary of an induction motor feeds current to another motor. Here the secondary motor is of the commutator type. The feature of this arrangement which makes the commutator motors operative in general, lies in the low frequency delivered by the secondary of the induction motor to the commutator motor. At synchronism of the induction motor, the frequency of the secondary is zero. If the speed is within 10 per cent of synchronism, for instance, the secondary frequency will be 10 per cent of the primary frequency; that is, with 60 cycles in the primary the secondary frequency would be six cycles. At a speed of 30 per cent from synchronism, the secondary frequency will be 30 per cent, or 18 cycles, with a 60-cycle supply circuit. These low frequencies are particularly advantageous in the design of commutator type alternating current motors whether of the single-phase or three-phase type. However, the further the speed departs from synchronism the more difficult becomes the design and operating conditions. In consequence, such systems are usually built to operate within a certain limited per cent of synchronous speed, this per cent depending upon the frequency of the supply circuit. These conditions apply to the arrangement shown in Figs. 34 and 36. However, in the scheme shown in Fig. 35, the current from the secondary of the induction motor is fed to the collector rings of a synchronous converter and direct current from this synchronous converter is fed to a direct current motor, which thus absorbs the extra power of the secondary to the main motor.

A little consideration will show that the synchronous converter should be of the same capacity as the motor to be regulated, if operated at the primary frequency. It is therefore necessarily a large and expensive machine, relatively speaking. The lower frequency and the lower speed at which it is normally operated will be of indirect advantage in somewhat reducing the cost and size of this synchronous converter.

Furthermore, the direct-current motor operated from this synchronous converter cannot be of very economical proportions for it must be designed for operation over quite a wide range of voltage due to the fact that the synchronous converter will give different voltages with different speeds, and the direct-current motor must be adapted for operation at these voltages.

Therefore, considering this scheme as a whole, it appears to me that equivalent results would be obtained if the synchronous converter were connected directly to the supply circuit, so that its direct-current side supplies current to a direct-current motor which drives the load. The synchronous converter could be of the synchronous booster type for varying the direct-current voltage delivered by it. The size and capacity of the synchronous booster would be dependent upon the range of voltage, and speed variation desired, like the direct-current motor in Fig. 35. Therefore, in this arrangement the synchronous converter would correspond in capacity to the synchronous converter shown in Fig. 35, while the direct-current driving motor would correspond in capacity to the induction motor, and the synchronous booster would correspond in capacity to the direct-current motor in the same figure. The scheme, as a whole, appears to me to be simpler than that shown and no more expensive. With either of these schemes the permissible range of speed could be fairly wide.

C. P. Steinmetz: While the alternating-current motor has the reputation of being a constant speed motor, you see from the paper that in recent years a very large amount of work has been done in developing not only one but quite a number of types of variable speed alternating-current motors, although the work is so recent that these motors have thus far come into industrial practice only to a limited extent, and there is no doubt that many further developments are still possible and desirable. There is one feature which impresses itself very forcibly, and that is, that in most of these variable speed alternating-current motors, the variable speed is connected with the use of the commutator. A commutator is not necessarily objectionable. We know that the direct current motor has a commutator and can be extremely successful. But, on the other hand, as the great advantage of the alternating-current motor has always been claimed its great simplicity, due to the absence of commutator or similar device. When we wish to get variable speed, in most cases we have to accept the commutator—the same complication which is inherent in the direct current motor whether variable speed or constant speed.

In order to see how far we have advanced, and what further work may still be done, it is desirable to make a classification of the problem. The Standardization Rules divide the motors in two types: constant speed and variable speed motors. Of the variable speed motors, three classes again are distinguished: multispeed motors, which have several steps of constant speed, hence, which can by adjustment be operated as constant speed motors not only at one but at two or more speeds; second, varying speed motors, in which the speed varies with the load as a rule decreasing with increase of load. Typical thereof is the direct-current series motor; third, adjustable speed motors, in which the speed can be adjusted to any desired value within a certain range, but when once adjusted the motor remains at this speed irrespective of the load, or approximately so. Typical of this class is the direct-current shunt motor with field control, where, by varying the field rheostat, you can set the speed at any desired value, and at that value it remains approximately from no load to over load.

Alternating-current motors of these three types can be produced as follows: Multi-speed motors are in industrial use to a considerable extent as induction motors without commutators—either by changing the number of poles, by some switchover device, or by concatenation of two motors, or by combining the two concatenated motors in one structure as an internally concatenated motor, or by a combination of several of these methods whereby we can then gain a considerable number of speed steps.

The varying speed motor also exists as a motor without commutator. It is the induction motor with slip rings and external rheostat. In this motor with increasing load the speed decreases. It has a characteristic in its speed torque relation similar to the direct current series motor, except that the speed is limited to a definite maximum speed, the speed of synchronism. But the limiting feature of this motor is that when the speed falls off, the efficiency also falls off. That is, at fractional speed you get correspondingly fractional efficiencies. The varying speed alternating current motor which is free from this dropping off of efficiency with dropping off of speed, is the commutator motor of the series type, or of the repulsion type, or of the combination type, the series-repulsion type, but, as stated, this is not as simple because it has a commutator.

The third type of variable speed motor is the adjustable speed motor, a motor which can be run at any constant value of speed, within a certain range. This motor does not yet exist in the commutatorless type, but it does exist in an almost infinite variety of commutator types of motor. Many of these are mentioned in the paper, but there exists no adjustable speed alternating current motor yet, which does not have a commutator, and this field is still open for development. It is this class of motor, which after all, would be the most useful, because very often in the industry we desire to be able to vary the motor speed over a moderate range as in cotton mills, to adjust it to the materials and the atmospheric conditions, so as to operate the mill at maximum efficiency. This means the ability of varying the speed, say, ten or twenty per cent, up or down, and still at any speed to have constancy independent of the load. In the absence of this motor there have been developed adjustable speed commutator motors which are in industrial use, are eminently satisfactory, but have not yet the simplicity of the plain induction motor.

In concluding, I may say, so far as my experience goes with the variable speed alternating-current motors, there are in use to a large extent: the induction motor with external rheostat as varying speed motor in hoisting work, in three-phase railroading, etc.; then there is in extensive use the multi-speed motor of the changed-pole type, and also to some extent, of the concatenated type; then there is in use the varying speed motor of the commutator type, as series and repulsion motor, and finally there is in use the adjustable speed motor of the so-called induction-repulsion type, especially in small units for general service.

C. O. Mailloux: It is remarkable what a transformation of feeling electrical engineers have undergone, in the last few years, in regard to the commutator. For a time, the commutator was charged with all the crimes in the electrical calendar; it was considered a great objection in connection with electrical machinery, in general. It was the fashion, among the partisans of the polyphase induction motor, to allege, as one of its most meritorious features, the entire *absence* of a commutator. It was very pleasing to me, at the last electrical Congress, at Turin, in the discussion on electric railways, before Section 5, where I had the honor to preside, to find evidence of a return to a spirit of greater toleration with respect to the commutator. The partisans of alternating-current systems of traction, at that Congress, were not as rabid as formerly, on the subject of " commutators ". The reason is that, in Europe, just now, the single-phase system of electric traction is in vogue; and that system, as we know, involves the use of a commutator-motor. That, of course, makes some difference. It is sufficient to change the opinion of many men who, some years ago, thought that a commutator-motor was not fit for traction purposes at all. Thus the " evil " of former days is fast becoming a " virtue." The old French proverb says: " *Chassez le naturel, et il revient au galop.*" (The nearest English equivalent is: " what is bred in the bone cannot be beaten out of the flesh "). Perhaps the commutator is much more " natural " than some people have been willing to admit. In dealing with the problems of speed-regulation, with alternating-current motors of any phase and type, we are obliged to come to the commutator, in order to increase the range of speeds obtainable, and to realize the fullest possibilities. It is the most " natural " thing to do, and it should have been done long ago. It is now being done because it cannot be put off any longer, presumably. Whatever may be the reason, the result will be to make the induction motor much more " fit " than it was or would ever be otherwise, for many applications, old as well as new, in competition with the direct-current motor.

Those of us who obtained their first practical experience with commutator machines, in the days when there were no others, were reconciled to commutator-motors. We were not afraid of them; and we knew that they could be made to do good work under any and all circumstances. For many purposes the commutator-motor did much better work than the commutatorless motor, even before the advent of the commutating pole, or the so-called "inter-pole" motor. Today, with the auxiliary or commutating pole, we are getting commutation which is absolutely satisfactory, if not absolutely faultless, in the case of direct-current motors of good design. The problem will not be quite as simple, however, with alternating-current motors. There are many difficulties here, due to electromagnetic phenomena and reactions which are not "in phase" with each other, and it is necessary to resort to compensating devices of various kinds to secure a line of commutation that is "stable"—which may not shift back and forth, describing an angle, during each period—and which "stays put" at least a portion of the time, same as in the direct-current motor. It is gratifying to find that considerable progress has been made in the adaptation of the commutator to polyphase motors, in the last few years. In that respect, the Europeans appear to be in the lead. During my recent trip abroad, I had occasion to learn something of the latest improvements made there in multi-speed, adjustable speed, and variable speed motors; and I was surprised at some of the results which are being obtained with alternating-current commutator motors. M. Latour, who is mentioned in the paper as the inventor of a method of speed-regulation involving the use of a commutator motor, has recently brought out some new methods of regulation which are of the greatest interest and merit. He kindly explained some of his methods to me and also gave me some results of practical tests and operation. I was astonished at the wonderful range of speed obtained, with motors of all sizes, with very satisfactory commutation, and with good power factor and efficiency. His results have not been excelled, and I doubt if they have been equalled, in this country. They are hard to match, even in Europe, and his methods have been adopted and are being used by several manufacturers, and they are being imitated by others there. M. Latour is one of the few alternanating-current specialists who never had *commutatorphobia*. It was he who first made a success of the single-phase commutator motor of the compensating type. (Even the German Patent Office had, ultimately, to give him the priority over all others). His recent work with polyphase commutator motors, evincing great originality, and producing valuable industrial results shows what can be done to make the commutator appear, even here, as a blessing in disguise. It is high time that the rest of the alternating-current designers and specialists should realize that the commutator not only need not, but that it should not, be banished from their "repertoire." With proper appreciation and treatment, its role may become as important and as useful here as in the case of the direct-current motors.

Gus A. Maier: It seems that in the discussion of the paper, the commutator of the motor is what practically everyone objects to. It is not considered desirable to go back to direct-current practice and use the commutator. We are agreed on that point, but there seems to be no way of getting away from it at the present time. The Europeans have done a large amount of work on the commutator motor and use it in many places. As far as I can learn, the commutation is fairly good, although I understand that the European standards of commutation are not as high as the American practice.

There is one point which has not been brought out which the advocates of the alternating-current motor can still hold on to, and that is, the voltage on the commutator is very low, compared to the line potential. It will probably run in the neighborhood of from 50 to 100 volts, and then with some sparking on the commutator, even if the commutator becomes black, it does not seem to affect the commutation or operation of the motor in any way. The Europeans are running these motors in various places, cotton mills, hoisting outfits, lathes, and using Scherbius sets in rolling mills, and Scherbius and Kraemer systems are giving very good results. I think it is up to the American engineers to follow closely the European developments and make improvements wherever possible, and I have no doubt the future will show some rapid progress in that direction.

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THE RELATIVE COSTS AND OPERATING EFFICIENCIES OF POLYPHASE AND SINGLE-PHASE GENERATING AND TRANSMITTING SYSTEMS

BY H. M. HOBART

Three-phase generating and transmitting systems have been employed on so extensive a scale that the capital and operating costs may be fairly closely determined for any given conditions. Of late years, however, serious and well-backed proposals have been made which have comprised as a prominent feature, the generation and transmission of single-phase electricity.[1]

In most of these cases the object in view in employing single-phase electricity has been the provision of high-pressure electricity for the operation of railway trains. Such single-phase railway trains are equipped with electrical apparatus whose characteristics are such that the average power factor at the generating station is about 0.75. When, however, the trains are equipped with continuous-current apparatus, the continuous-current being obtained from synchronous substations, then the substations are supplied with three-phase current and at unity power factor. The electricity as delivered *from* such substations, costs per kilowatt-hour materially more than when delivered *to* the substations. The increase in cost arises from three causes:

1. The interest, insurance, taxes, maintenance and ultimate renewals associated with the substation investment.

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[1] Many years ago, single-phase generation and transmission was widely employed but that was in the days when electrical undertakings were on a relatively small scale and the conditions in many respects were so different that the early work with the single-phase system is now of but little more than historical interest.

2. The cost of the energy wasted in the substation apparatus in the process of transformation.

3. The outlay at the substations for wages, oil and stores.

The first and second of these three items are nowadays much lower than was formerly the case. This is due to the realization of the importance and feasibility of so proportioning the apparatus that the average load on the substation shall constitute a very considerable percentage of the rated capacity of the apparatus at any time in circuit, and that the apparatus shall, in respect to commutation, nevertheless be fully equal to handling the instantaneous peaks of load to which it is subjected. These peaks of load may amount to three or more times the rated load. The art of designing transformers and synchronous converters is now so advanced that the proportions which I have just indicated represent best practice, for not only are the capital costs reduced as compared with former practice but there is the very important consideration that the "all-day" efficiency of the apparatus is greater than is the case when larger machines are operated with an average load which is only a small percentage of their rated load.

On these modern and preferable lines, some $20 per kilowatt of rated capacity installed is an outside figure for the capital outlay for complete 1200-volt substations. The efficiency will depend upon the load factor[2] of operation of the machinery in circuit and may be based on the following data:

Load Factor of machines in service.	"All-year" Eff.[3] of the substation.
0.30	0.86
0.40	0.88
0.50	0.90
0.60	0.91

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[2] In paragraphs 50 and 51 of the 1911 Standardization Rules of the A.I.E.E. (See p. 1927 of PROCEEDINGS A.I.E.E. for August, 1911), the term "load factor" is defined as follows: "The load factor of a machine, plant or system is the ratio of the average power to the maximum power during a certain period of time. The average power is taken over a certain period of time, such as a day or a year, and the maximum is taken over a short interval of the maximum load within that period. In each case the interval of maximum load should be definitely specified. The proper interval is usually dependent upon local conditions and upon the purpose for which the load factor is to be determined."

For the purposes of the present investigation, the load factor of the generating station is taken on this basis and the maximum power is taken as the maximum load averaged over sixty consecutive minutes at any time during the year. But in the case of the substations the available records and data are not of a character permitting of em-

The outlay for wages, oil and stores will be covered by taking it at the following values:

Load Factor	Outlay for wages, oil and stores (in substations), per kw-hr. of output from the substations
0.30	0.14 cent[4]
0.40	0.12 "
0.50	0.10 "
0.60	0.09 "

I shall proceed from these data in working out, (in a later section of this paper), the cost of the electricity delivered from the substations and I shall ultimately arrive at the result that when the load factor on the substations is of the order of 0.50, the cost of the electricity as delivered from the substations is, per kw-hr., usually of the order of some 18 per cent greater than the cost of 0.75-power-factor single-phase electricity of the pressure appropriate for delivery to the train. This is in striking contrast to figures which have been quoted. Thus in the course of the discussion of some papers at the Institution of Mech. Engineers on July 29, 1910, (see p. 1233 of Proc. Inst. Mech. Engrs., for 1910), it was stated that the cost of continuous-

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ploying this conception of the load factor. Hence so far as relates to the substations I have taken the load factor as the ratio of the average load on the machines in circuit, to their rated loads.

3. Mr. Aspinwall, general manager of the Lancashire & Yorkshire Railway, has shown (Proc. Inst. Mech. Engrs., 1909, Part 2, p. 454) that for 57,190 kw-hr. delivered from the substations of the Southport Railway, on a certain day in July, 1906, there was a loss of 3,480 kw-hr. in the rotary converters, and a loss of 1,885 kw-hr. in the transformers. Consequently for the service on that road on the day in question, the overall efficiency of the substations was

$$\frac{57{,}190}{57{,}190+3480+1885}\times 100 = 91 \text{ per cent.}$$

4. In a paper by B. F. Wood, entitled "Electrical Operation of the West Jersey and Sea Shore Railway" the costs of "operation and maintenance" of the eight substations of that road are shown to have amounted to 0.108 cents per kw-hr. of output for the year 1910. The two components are given as:

Operation	$20,852
Maintenance	3,607
Total	$24,459

Consequently the outlay for operation (exclusive of maintenance) was

$$\frac{20{,}852}{24{,}459}\times 0.108 = 0.092 \text{ cents per kw-hr.}$$

These were 675-volt substations (See Table IV on p. 1770 of PROCEEDINGS American Institute Electrical Engineers, for August, 1911).

current as delivered from the substations would exceed the cost of single-phase current not by 18 per cent but by "50 or 60 per cent."

Another instance of the contention that the cost of continuous current as delivered from substations is necessarily greatly in excess of the cost of single-phase current as delivered from distributing cabins, is found in the following quotation from a paper entitled "London to Brighton in Forty-Five Minutes," read by Mr. Philip Dawson at The Royal Automobile Club, on Dec. 8, 1911:

"In England to-day, electricity for traction purposes is being generated by steam at a works cost of 1/4d. per unit; on to this must be added the capital charges, which will vary according to the nature and size of the power plant and its location and load factor. In America, works cost is as low as 0.22d. per unit in a station which consumes 2.9 lb. of coal per klwt. hour. Capital charges should not exceed 0.2d, so that it is quite conceivable that railways will, in the future, be able to purchase alternating current in this country at 0.4d. to 0.45d. per unit, delivered to them on their railway, and this will be the total cost to the company if alternating current is used. On the other hand, if continuous current is adopted, this figure will be increased by the losses sustained in the course of transformation, and by the low-pressure distributing losses, as well as by the costs involved in the substations, as regards working, maintenance and capital charges. Some idea of what these may amount to may be gained from the fact that in the case of the New York Central Railroad, according to Mr. Wilgus, the cost of substation transformation and distribution is 0.158d. per unit, whilst the capital charges due to this item are 0.455d., thus making a total of 0.613d. per unit for transformation alone, a truly collossal amount. This need not be so great in every case, but, under such favourable conditions as exist in London on the County Council tramways, this figure is represented by 0.26d., or a figure larger than the total works cost at the generating station. This would increase the cost of current to the railway by at least 50 per cent., making the cost of continuous current delivered to the line 0.6d. to 0.675d. per unit. This is a very important consideration, when it is remembered that the cost of current represents about 50 to 60 per cent of the total locomotive charges per train mile."

These are specific but typical instances of the general impression held in many quarters with respect to the relative costs of these two forms of electricity, and the result is that engineers are apt to be too sanguine as regards the ultimate cost of the single-phase system of operating railways. It is possible that the single-phase system may play an important part in certain classes of railway electrification work, such as for hauling freight trains and express passenger trains, but in the interests of railway electrification, it is important to confine the application of the single-phase system to its true economic range of work, or at any rate, to classes of work not widely outside of this range. Furthermore a correct comprehension of the matter will lead usually to employing polyphase generation and transmission even when the distribution is single-phase.

I have therefore considered that it will be well worth while to trace through two cases. In the first of these two cases the generation and transmission are three-phase, and the three-phase current is transformed into continuous current in synchronous substations equipped with step-down transformers and synchronous converters. In the second case the generation, transmission and transformation are single-phase.

In confining my examination to turbo-electric generating sets it should not be inferred that I ignore the possible imminence of the advent of the internal-combustion engine. It would be too distracting to introduce too many alternatives into the comparison. In adhering to the steam-turbine as prime-mover, the case is more favorable to the single-phase proposition than is a comparison with slower-speed prime-movers, for reasons which will be apparent from the estimates worked out in this paper for the turbo-electric propositions.[5]

Let us first consider a three-phase generator. Let its rated output be 8000 kilovolt-amperes. Since it will supply energy to substations equipped with *synchronous* apparatus, its rated output will also be 8000 kilo*watts*, (kw.). An entirely suitable periodicity, so far as relates to the preferable conditions of operation of synchronous substation machinery, is 25 cycles per second. The maximum possible speed for a 25-cycle set is 1500 rev. per. min., corresponding to a bipolar generator. At the present state of development of turbo-generators, this speed of 1500 rev. per min. is practicable for a set of this rating[6] and leads to the best results as regards steam economy. The electric generator for such a set weighs some 100 tons. Now in what respect will a single-phase generator suitable for this same prime-mover, differ from the above-indicated three-phase generator? In the first place, the stator will be furnished with a three-phase Y-connected winding indentical with that which would be provided if the set were intended to supply polyphase electricity. Only two of the three windings are employed at any one time, but it has proved best practice to mount all three windings in place as this permits of having a winding in reserve as a spare for use in the event of a breakdown of either of the other two branches of the Y-winding. Thus for a single-phase load of 8000 kv-a. we require a generator which is appropriate for a *three-phase* load of 12,000 kv-a. and we are only able to make use of the windings on two-thirds of the stator periphery. But the case is much less favorable even than this would indicate. Instead of a load of *synchronous* machinery adjusted for *unity* power factor, a single-phase railway, fed directly from the generating station and without the intermediation of synchronous machinery, will constitute a load with an average power factor of some 0.75. Then instead of requiring a three-phase capacity of 12,000 kv-a. the generator will, for the same kilowatts load, (*i.e.*, a load of 8000 kw.), require a three-phase capacity of $\frac{12,000}{0.75} = 16,000$ kv-a.

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[5] Briefly, the reasons are that the armature $I^2 R$ loss is a larger percentage of the rated load and the core loss a smaller percentage, the lower the rated speed. Now, as is explained later in the paper, the losses in the single-phase generator include a loss in addition to those in the three-phase generator. This loss is in the winding which suppresses the flux changes due to the pulsating armature magnetomotive force. The loss in this extra winding is of the same order of magnitude as the $I^2 R$ loss in the armature winding. Consequently the inferiority in efficiency of the single-phase generator as compared with the three-phase generator is greater the lower the rated speed. In this paper I am favoring the single-phase generator by working out my comparisons for the very highest speeds which can be considered commercial.

In other words, we shall, for a given kilowatt load for a single-phase railway, require a generator of just about twice the three-phase kv-a. capacity that would be required for the same kilowatt load of synchronous three-phase substation apparatus. Now in the present state of the art, a 16,000-kv-a. 25-cycle synchronous three-phase generator would be beyond the range for which a bipolar construction could appropriately be employed, and it would be built with four poles and with a speed of only 750 rev. per min. It would not have quite so low a steam consumption as would a 1500 rev. per min. set. I have already explained that to obtain a single-phase output of 8000 kw. at a power-factor of 0.75 we should require a generator which, if employed as a three-phase machine, would have a rating of 16,000 kw. at unity power factor. Since this would be so large a generator that it would not be desirable to build it for a speed of 1500 rev. per min., it would be necessary in a single-phase station, to either have twice as many sets as in a three-phase station, each set being of only half the capacity, (in which case we *could* employ a speed of 1500 rev. per min.), or else we could have the same number of sets as in the three-phase station, but designed for 750 rev. per min. as against the speed of 1500 rev. per min. employed in the three-phase sets. The practical decision would be to employ the latter plan. In that case, while our 8000-kw., 1500-rev. per min., unity-power factor, three-phase electric generator would weigh about 100 tons, our 8000-kw., 750-rev. per min., 0.75-power factor, single-phase electric generator would weigh fully 240 tons and would not only cost over twice as much, but the turbine by which it would be driven would have a slightly higher steam-consumption per kilowatt-hour of output than would be the case with the 1500-rev. per min. turbine for driving the three-phase generator. But for the purposes of the present comparison I have determined that instead of handicapping the single-phase proposition with the additional weight and slightly higher steam consumption consequent upon the employment of only half the speed adopted for the three-phase generating set, and in the interests of simplifying the comparison, I will credit the single-phase set with the advantages of the higher speed of 1500 rev. per min. I shall arrange for this by assuming that the steam turbine of a single-phase generating set is direct-connected to *two* single-phase generators whose *combined* capacity is 8000 kw. at a power factor of 0.75, each component generator having only a single-phase (0.75 power factor) capacity of 4000 kw. The use of this plan for the purpose of simplifying my calculations is entirely legitimate, since it leads to crediting the single-phase proposition with fully as low a weight and cost for the generating sets and with a slightly lower steam consumption than would obtain with the plan which would, in practice, be followed, namely, to employ a turbine with a speed of only 750 rev. per min. coupled to only one single-phase generator of the full required capacity. Thus the 8000-kw., 0.75-power factor, single-phase generating set is, for the purposes of my calculations, composed of a single steam turbine driving, at a speed of 1500 rev. per min., two 4000-kw., 0.75-power factor, single-phase generators.

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[6] At first sight it may occasion surprise that I put forward 1500 rev. per min. as an appropriate speed for a 25-cycle, 8000-kw. generator. But the tendency toward high speeds is now very strong and we already have 2500-kw., 60-cycle generators for a speed of 3600 rev. per min. With this rating of 2500-kw. at 3600 rev. per min. in mind, a rating of 8000-kw. at 1500 rev. per min. is seen to be by no means extreme.

Each one of these component single-phase generators will be more heated when carrying its load of 4000 kw. at 0.75-power factor, than it would be heated when carrying a three-phase load of 8000 kw. at unity power factor. This statement may be challenged and I may be reminded that with the single-phase load, only two-thirds of the windings will be carrying current and that consequently the stator $I^2 R$ loss will only be two-thirds as great in each machine. But we must take into account the consequences of a very important factor, namely, the fluctuating nature of the armature reaction of single-phase generators. This fluctuating armature reaction, if not compensated, entails a very large loss in portions of the magnetic circuit. In a three-phase generator, the armature strength opposite any reference part of the periphery of the rotating field does not change in value and consequently a three-phase generator is immune from any such loss. If, in a single-phase generator, we do not provide a compensating winding, the loss in question will often be so great as to preponderate over the sum of all the other losses and will lead to impracticable conditions as regards excessive temperature rise and low efficiency. But in all modern single-phase generators a suitable compensating winding is provided at the surface of the internal rotating field and this compensating winding usually takes the form of a squirrel cage. The lower the resistance of this compensating winding, the smaller will be the $I^2 R$ loss occurring in it. Space limitations will rarely permit of employing in this pole-face winding a greater aggregate cross section than is provided by the stator conductors, (indeed it is rarely possible to find space for a compensating winding with an aggregate cross section so great as the aggregate cross section of the stator winding). If the aggregate cross section of the stator conductors and of the conductors of the squirrel-cage winding are made the same, and if this suffices to render substantially negligible the loss in the magnetic circuit, then this result will have been achieved at the cost of the introduction of a loss in the pole-face winding which will be about equal to the loss in the stator winding (*i. e.*, to the armature I^2R loss.) Now in a 1500-rev. per min., two-pole, 8000-kw. unity power-factor, three-phase generator, the losses in the machine at full load (exclusive of bearing friction) will be somewhat as follows:

Armature I^2R loss	20 kw.
Field " "	20 "
Core loss	70 "
Windage loss	100 "
Total loss at full load	210 kw.
Output " " "	8000 "
Input " " "	8210 kw.
Eff. (excl. of bearing friction)	97.4 per cent

When built for and operated at a power factor of 0.75 and with a three-phase output of 8000 kv-a. ($8000 \times 0.75 = 6000$ kw.), the field excitation will be higher (for the same terminal pressure) and the losses and efficiency will be somewhat as follows:

Armature I^2R loss	20 kw.
Field " "	30 "
Core loss	70 "
Windage loss	100 "
Total loss	220 "
Output	6000 "
Input	6220 kw.
Eff. (excl. of bearing friction)	96.5 per cent.

If this machine is operated single-phase with 0.75 power factor and an output of 4000 kw. ($0.667 \times 8000 \times 0.75 = 4000$ kw.) the losses and efficiency will be about as indicated below:

Armature I^2R loss	13 kw.
Pole face winding I^2R loss	13 "
Field I^2R loss	25 "
Core loss	70 "
Windage loss	100 "
Total loss	221 "
Output	4000 "
Input	4221 kw.
Eff. (excl. of bearing friction)	94.8 per cent

From these figures we see that to provide from the two machines 8000 kw. of single-phase current at 0.75 power factor, we shall have in each of the machines a loss of 221 kw. (or 422 kw. in the combined 8000-kw. set), as against a loss of only 210 kw. in only one of the machines when operated three-phase at unity power factor. Incidentally the three-phase, unity power-factor installation will have some 6 per cent to 8 per cent inherent regulation whereas the inherent regulation of the single-phase, 0.75 power-factor installation will be of the order of 15 per cent or worse and will thus be so inferior as to require that some type of automatic regulators shall be provided. This, however, is but a relatively trifling disadvantage. In view of the above comparison, it is seen that twice the weight of electric generators will, for a given available power, be required for the single-phase proposition as compared with the proposition employing synchronous three-phase substations. In fact the case is still worse, as I shall now explain. The interposition of the rotating apparatus in the substations, even without the use of storage batteries, serves to buffer the instantaneous peaks of load which attend the operation of trains. Consequently in the three-phase system with substations, the crest loads at the generating stations will, for a given train service, less exceed the average load than is the case where the same train service is handled by the single-phase system. In other words, the load factor of the generating station will be higher with the three-phase system, and consequently less rated capacity will be required to be installed for a given annual output of electricity from the generating station. But I do not propose in my quantitative comparison to take into account this further disadvantage of the single-phase system.

Let us consider a station with six such 8000-kw., 1500-rev. per min. steam turbines, and let us work out a rough comparative estimate for the costs of the generating sets; both for three-phase with unity power-factor and for single-phase with 0.75-power factor. We may, with sufficient correctness for a comparison of this sort, take the market price of the three-phase generators at $400 per metric ton, (*i.e.*, per ton of 1000 kg. or 2204 lb). Leaving out of account, for the moment, the cost of the single-phase generators' squirrel-cage compensating winding and the outlay for the greater amount of main field winding which they require, the market price of the single-phase generators may also be taken at $400 per ton, for, with the exceptions noted, they are identical with the three-phase generators. Each of the component generators would weigh a matter of 100 tons and would consequently cost 100×400 = $40,000. But we may take the outlay for the squirrel-cage compensating winding and for the additional copper in the main field winding as increasing the cost of each component single-phase generator by some six per cent, bringing it to 1.06×40,000 = $42,500. Thus for the single-phase station the outlay for generators aggregates 12×42,500=\$510,000, whereas for the three-phase, unity-power factor station of the same total rated kilowatts capacity, the outlay for the generators would only amount to 6×40,000=\$240,000. But for the single-phase generators the installation of exciters will also have to be greater, and furthermore (on account of the inferior inherent regulation at 0.75 power factor) an additional outlay (though slight) must be incurred for automatic regulators. There is the additional consideration that the turbo-electric generating sets will be much larger and heavier, thus increasing the outlay for foundations and increasing the size of the engine room. These further outlays may be fairly taken as covered by \$30,000. Thus the cost of the single-phase generating station will exceed that of the polyphase generating station by some 510,000+30,000 −\$240,000=\$300,000. The total cost of a modern three-phase generating station with a rated capacity of 48,000 kw. of installed machinery amounts to about \$70 per kilowatt, the precise value depending upon many circumstances pertaining to each particular case. At \$70 per kw., the total cost amounts to \$3,360,000. Thus we see that the \$300,000 difference in cost between a three-phase, unity power-factor generating station and a single-phase 0.75 power-factor generating station amounts to a difference of some

$$\frac{300{,}000}{3{,}360{,}000} \times 100 = 8.94 \text{ per cent}$$

or, say, 9 per cent in the capital outlay. A generating station of this rated capacity and for a load factor of 0.5 is suitable for supplying at its outgoing cables some 160 million kilowatt-hours per year. At an "all-year" efficiency of 12 per cent from the coal-pile to the generator switchboard and with coal of a thermal quality represented by 13,400 B.t.u. per lb., (8700 kw-hr. per metric ton),[9] the annual coal consumption will be:

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[9] This is a very instructive way in which to view the subject. A pound of coal of a calorific value of 13,400 B.t.u. may also be stated to have a calorific value of $\frac{8700}{2204}=3.94$ kw-hr. per lb. That is to say, if the efficiency from the coal pile to the generator switchboard were 100 per cent, the coal consumption would be $\frac{1}{3.94}=0.254$ lb. per kw-hr. In assuming the high overall efficiency of 12 per cent, I am assuming a

$$\frac{160{,}000{,}000}{0{,}12\times 8700}=153{,}000 \text{ metric tons}$$

or

$$\left(\frac{2200}{2000}\times 153{,}000=\right) 169{,}000 \text{ (short) tons}$$

At $2.00 per (short) ton, the annual outlay for fuel amounts to:

$$2.00\times 169{,}000=\$338{,}000.$$

We have seen that the efficiency of the single-phase generators is (97.4 − 94.8 =) 2.6 per cent less than that of the three-phase generators. The greater coal consumption of the single-phase generating station thus results in a greater fuel outlay and the amount of this greater outlay is some 0.026 × 338,000 = $8,800. As a matter of fact, while the single-phase generators have a 2.6 per cent lower efficiency at their rated load, this inferiority is more of the order of 3½ or 4 per cent for the varying loads of actual practice and I am favoring the single-phase system in not taking this greater difference into account.

Assessing at 15 per cent the interest on the $300,000 worth of machinery and the annual outlay for insurance, taxes, maintenance and ultimate renewal, the greater annual cost of the single-phase generating station as compared with the three-phase generating station amounts to 0.15 × $300,000 + $8,800 = $45,000 + $8,800 = $53,800. Since the annual output is

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coal consumption of $\frac{1.00}{0.12}\times 0.254=2.12$ lb. per kw-hr. If I had assumed a lower overall efficiency (*i.e.*, a higher coal consumption in lb. per kw-hr. of output,) the comparison would have been more to the disadvantage of the single-phase system.

On p. 1776 of the PROCEEDINGS A.I.E.E. for August, 1911, in the course of the paper by Mr. B. F. Wood on the "Electrical Operation of the West Jersey & Seashore Railway," it is shown that for the last four years, the total output per year and the coal consumption were as shown in the following table, in which I have added a column for the overall efficiency from the coal pile to the outgoing cables from the power station on the basis of a calorific value of 13,400 B.t.u. per pound.

Year	Output in Millions of kw-hr.	Lb. of Coal per kw-hr. of output	Overall Efficiency
1907	21.1	3.67	6.94 per cent
1908	22.9	3.37	7.54 " "
1909	23.6	3 30	7.70 " "
1910	28.3	3.25	7.81 " "

160 million kilowatt-hours, the difference in cost may be expressed as $\frac{53{,}800\times 100}{160{,}000{,}000}=0.0336$ cent per kw-hr. For a station of this size and for coal at $2.00 per ton and with a plentiful and inexpensive supply of condensing water, the cost for three-phase electricity at the generator switchboard for a load factor of 0.50 is of the order of about 0.8 cent per kw-hr. This is rather a high figure but for the present strictly comparative investigation it is thoroughly appropriate.

In order to contrast the relative costs of three-phase, unity-power factor electricity and single-phase, 0.75-power factor electricity as delivered to the generator switchboard let us take the cost as

$0.8-0.0168=0.783$ cent per kw-hr. for three-phase current.
$0.8+0.0168=0.817$ cent " " " single-phase "

It is seen that the difference in cost at this stage is 4.2 per cent.

Usually the appropriate generating pressure is very much lower than the appropriate transmitting pressure and there must be taken into account the step-up transformers intermediary between the generators and the transmission line. For a project of this size, the transformer units will be very large and may, for the three-phase, unity power-factor proposition, be taken as having an "all-year" efficiency of 97.5 per cent for the conditions of load under which they operate. Owing to the 0.75 per cent power factor of the single-phase proposition, it will be necessary to provide 33 per cent more kilovolt-amperes capacity to transformers for the single-phase than for the three-phase plant. The purchase price of large step-up transformers appropriate for such a plant will be of the order of $2.50 per kilovolt-ampere of rated capacity of the plant. Thus we have for the total cost of the step-up transformers

$48{,}000\times 2.5=\$120{,}000$ for the three-phase plant, and
$1.33\times 48{,}000\times 2.5=\$160{,}000$ " " single-phase "

Since the losses in the three-phase transformers amount to 2.5 per cent of the input, the losses in the single-phase, 0.75 power-factor transformers will amount to $(1.33\times 2.5=)$ 3.3 per cent of their input, *i. e.*, their "annual" efficiency is 96.7 per cent. The interest, insurance, taxes, maintenance and ultimate renewal may be taken at 10 per cent for the transformers. The respective values of 2.5 per cent and 3.3 per cent representing the losses in the transformers will represent an annual cost of

$$\frac{160{,}000{,}000\times0.783\times0.025}{100}=\$31{,}300$$

for the three-phase scheme, and

$$\frac{160{,}000{,}000\times0.817\times0.033}{100}=\$43{,}500$$

for the single-phase scheme.

The total annual cost associated with the step-up transformers therefore amounts to

120,000×0.10+31,300=$43,300 for the three-phase scheme, and
160,000×0.10+43,500=$59,500 for the single-phase scheme.

On the basis that 160 million kw-hr. are annually delivered from the high-pressure side of these step-up transformers, the increase in cost occasioned by the transformers amounts to:

$$\frac{43{,}500\times100}{160{,}000{,}000}=0.0270\text{ cent (or say }0.027\text{ cent) per kw-hr. for}$$

the three-phase scheme, and

$$\frac{59{,}500\times100}{160{,}000{,}000}=0.0372\text{ cent (or say }0.037\text{ cent) per kw-hr for}$$

the single-phase scheme.

The cost of the electricity as delivered to the transmission line is thus:

0.783+0.027=0.810 cent per kw-hr. for the three-phase scheme, and
0.817+0.037=0.854 cent " " " " single-phase scheme.

Let us next examine the transmission line for the two cases. To fix ideas, let the distance be 35 miles (56.3 km.) and let the transmission be by overhead conductors carried by steel towers.

In the case of the single-phase line, the annual delivery at the distant end of the line of 150 million kw-hr. of energy will be associated with the transmission of 33 per cent more kilovolt-ampere-hours, since the power factor is 0.75 as against the power factor of unity for the three-phase line. Let us employ the same total cross-section of copper in both cases. Then if the line loss is taken at 8 per cent for the single-phase line, it will be only

$\frac{8}{1.33^2} = 4.5$ per cent[10] for the three-phase line. The capital outlay will be the same for both cases, and, for pressures in the economical range, the total cost will run to some $20,000 per mile, or $700,000 for the complete 35-mile line.[11] The annual outlay for interest, right-of-way, upkeep, and ultimate renewals may be taken at 12 per cent. This amounts to $700,000 \times 0.12 =$ $84,000 per annum. If 150 million kw-hr. are annually delivered at the distant end of the line, then the line loss is, for the three-phase proposition,

$$\frac{150,000,000}{0.955} - 150,000,000 = 7,000,000 \text{ kw-hr.}$$

and for the single-phase proposition it is,

$$\frac{150,000,000}{0.92} - 150,000,000 = 13,000,000 \text{ kw-hr.}$$

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[10] In the following estimate I am assuming that in the single-phase proposition, the pressure between conductors will be 15 per cent higher than in the three-phase line. If I imposed the condition that the pressure between conductors should be no greater than in the case of the three-phase proposition, then the line loss would be (for the same total cross-section of copper in the two cases):

For the three-phase line, 4.5 per cent.
" " single-phase line, $1.15^2 \times 8.0 = 10.6$ per cent.

But for overhead transmission lines there is no sufficient reason for not adopting the higher pressure in the case of the single-phase proposition. But a consideration of this point brings out strongly the desirability of employing step-up and step-down transformers in single-phase transmission lines of any considerable length and for any considerable amounts of power. The proposition to employ the generator pressure on the transmission line will usually lead to severe limitations as regards the distance between generating stations. In our propositions, the economical pressure between lines will be of the order of:

30,000 volts for the three-phase line
35,000 " " " single-phase line

If the single-phase line had also been restricted to 30,000 volts, the loss in it would have been 10.6 per cent instead of 8 per cent.

[11] Opinions will differ with regard to the appropriate outlay per mile for transmitting the quantity of energy under consideration. For railway purposes a distinctly liberal construction would seem justified. However, instead of regarding this transmission as a straight run of 35 miles, we may regard it as a transmission line costing $700,000 and involving, when dealing with 150,000,000 kw-hr. per annum, a line loss of 8 per cent in the single-phase proposition and of 4.2 per cent in the three-phase proposition.

The annual cost of the energy lost in the line is:

Three-phase $7{,}000{,}000 \times 0.00810 = \$56{,}700$
Single-phase $13{,}000{,}000 \times 0.00854 = \$111{,}000$

The total costs associated with the transmission are:

Three-phase $\$84{,}000 + \$56{,}700 = \$140{,}700$
Single-phase $\$84{,}000 + \$111{,}000 = \$195{,}000$

Reducing this to the cost per kw-hr. delivered, we have:

$$\text{Three-phase } \frac{140{,}700 \times 100}{150{,}000{,}000} = 0.094 \text{ per kw-hr.}$$

$$\text{Single-phase } \frac{195{,}000 \times 100}{150{,}000{,}000} = 0.130 \text{ per kw hr.}$$

This gives us for the cost of the electricity as delivered at high pressure at the distant end of the line:

Three-phase $0.810 + 0.094 = 0.904$ cent per kw-hr.
Single-phase $0.854 + 0.130 = 0.984$ cent per kw-hr.

At this point, the cost of the single-phase electricity is 9.0 per cent greater than the cost of the three-phase electricity. But in stepping-down the pressure for distribution to railways, the single-phase electricity need only be passed through static transformers. These will be more numerous and smaller than those required for stepping-up the entire output of the generating station. Their purchase price can appropriately be taken at $4 per kv-a. and their aggregate rated capacity will be about

$$1.5 \times 48{,}000 \times 1.33 = 96{,}000 \text{ kv-a.}$$

The further outlay for buildings and switch gear for these single-phase substations or distributing cabins may be taken as $0.30 per kv-a. Thus the outlay for step-down transformers together with buildings and switch gear will be:

$$96{,}000 \times (4.00 + 0.30) = \$412{,}000$$

The annual losses in the step-down transformers may be taken as 3 per cent of the energy delivered to them in the case of the three-phase transformers and as ($1.33 \times 3 =$) 4 per cent of the energy delivered to them in the case of the single-phase transformers, their annual efficiencies thus being taken as 97.0 per cent and 96.0 per cent respectively. As this is the final transformation, let us make a rough estimate of the losses incurred, and at the various stages.

Up to and including the steam turbines the two propositions have the same efficiency. That is to say, for the consumption of a given quantity of coal, the same amount of energy will in both cases be delivered to the generators. From this point onward, the efficiencies are of the percentages set forth in the following table:

	Three-phase and unity power-factor	Single-phase and 0.75 power-factor
Generators	0.974	0.948
Step-up transformers	0.975	0.967
High-pressure line	0.955	0.920
Step-down transformers	0.970	0.960
Synchronous converters (for a load factor of 0.50)	0.930	.....

The aggregate "annual" efficiencies from the steam turbines up to the points where the electricity is delivered into the distribution system, are obtained as follows:

Three-phase system with synchronous converters and with unity power factor,

$$0.974\times0.975\times0.955\times0.970\times0.930=0.816, =81.6 \text{ per cent.}$$

Single-phase system with 0.75 power factor:

$$0.948\times0.967\times0.920\times0.960=0.810, =81 \text{ per cent.}$$

Thus quite contrary to the usual belief, the single-phase system has, in such a case as that which I have worked through, no greater overall efficiency than the three-phase system with rotary-converter substations.[12]

If we start from the basis that about 167 million kw-hr. of energy are annually delivered from the steam turbines to the

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[12] It may be of interest to call attention to the efficiencies obtained on the West Jersey & Sea Shore Railroad. The figures apply to the efficiency from the "Power Station Bus to Substation Bus" and are given on p. 1776 of the PROCEEDINGS A.I.E.E. for August, 1911 in the course of a paper by Mr. B. F. Wood entitled "Electrical Operation of the West Jersey and Sea Shore Railway." The results are as follows:

Year of Operation	Annual output from generating station	Efficiency between power station bus and substation bus
1907	21,100,000 kw-hr.	72.2 per cent
1908	22,900,000 "	73.8 " "
1909	23,600,000 "	78.4 " "
1910	28,300,000 "	81.6 " "

It is to be observed that these figures related to a much smaller system than the one I have selected for my calculations. On the other hand, my figure of 81.6 per cent includes 2.6 per cent in the main generators

generators, then, in both propositions, the amount finally delivered to the distribution system is just about

$$0.81\times 167{,}000{,}000=135{,}000{,}000 \text{ kw-hr. per annum}$$

In the three-phase proposition, the three-phase current is transformed into continuous current in synchronous substations. For a load factor of 0.50 a liberal figure for the aggregate rated capacity of these substations is

$$1.50\times 48{,}000=72{,}000 \text{ kw.}$$

At $20 per kw., the total outlay for substations amounts to

$$20\times 72{,}000=\$1{,}440{,}000$$

Taking interest, insurance, taxes, maintenance and ultimate renewal at 13 per cent the annual outlay amounts to

$$0.13\times 1{,}440{,}000=\$187{,}000$$

The annual efficiency of the substations is 90 per cent and the loss per annum amounts to

$$\frac{135{,}000{,}000}{0.90}-135{,}000{,}000=15{,}000{,}000 \text{ kw-hr.}$$

This loss represents a cost of

$$\frac{15{,}000{,}000}{100}\times 0.904=\$136{,}000$$

Wages, oil and stores will, (see table on p.161,) amount to an annual outlay of some

$$0.0010\times 135{,}000{,}000=\$135{,}000$$

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and 2.5 per cent in the step-up transformers. Consequently for the efficiency from the high-pressure bus in the generating station to the substation bus, my result would be

$$\frac{0.816\times 100}{0.974\times 0.975}=86.0 \text{ per cent.}$$

On the West Jersey & Seashore Railroad, the transmission line is 60 miles (96.5 km.) in length and presumably the line loss is greater than would be appropriate in the hypothetical case which I have taken as a basis for my estimate. If my line loss were doubled, the above figure of 86.0 per cent would come down to 81.5 per cent.

Thus the total annual outlay which should be allocated to the synchronous substations is

$$\$187{,}000+\$136{,}000+\$135{,}000=\$458{,}000, \quad \text{or}$$

$\dfrac{458{,}000\times 100}{135{,}000{,}000}=0.339$ cent per kw-hr. delivered from the substations.

This brings the cost of the electricity, at the outgoing cables from the substation, up to

$0.904+0.339=1.243$ cents per kw-hr., or, say, 1.25 cents per kw-hr.

Now let us return to the single-phase proposition. The annual capital outlay on account of interest, insurance, taxes, maintenance and ultimate renewal of the step-down transformers and buildings and switch gear may be taken as

$$\$412{,}000\times 0.10=\$41{,}200$$

this being 10 per cent on the capital outlay. The losses in them amount, per year, to

$$\frac{135{,}000{,}000}{0.96}-135{,}000{,}000=5{,}800{,}000 \text{ kw-hr.}$$

These represent an annual outlay of

$$\frac{0.984\times 5{,}800{,}000}{100}=\$57{,}000$$

which, added to the capital outlay, makes the total annual outlay associated with the step-down transformers

$$\$41{,}200+\$57{,}000=\$98{,}200 \quad \text{or}$$

$$\frac{98{,}200\times 100}{135{,}000{,}000}=0.073 \text{ cent per kw-hr.}$$

This brings the final cost of the single-phase electricity to

$0.984+0.073=1.057$ cent per kw-hr. or, say,
1.06 cents per kw-hr.

Thus we have:

Cost of continuous current as delivered from the synchronous substations

1.25 cents per kw-hr.

Cost of single-phase electricity as delivered from the secondaries of the step-down transformers in the distributing cabins

1.06 cents per kw-hr.

$$\frac{1.25}{1.06} = 1.18$$

Thus it is seen that for the 0.50 load-factor case we have considered, the continuous current can be provided at a cost of the order of only some 18 per cent greater than the cost of the single-phase electricity and at the same overall efficiency from the coal pile to the distribution system. The capital cost in the two cases is shown in the following table:

	Three-phase unity power-factor proposition	Single-phase, 0.75 power-factor proposition
Generating station....................	$3,360,000	$3,600,000
Step-up transformers..................	120,000	160,000
Transmission line........................	700,000	700,000
Distributing cabins with stationary step-down trans..................	....	412,000
Synchronous substations with step-down trans. and synchronous converters.	1,440,000	....
Total capital cost....................	$5,620,000	$4,932,000

To more readily grasp the general significance of these results we may use the following approximations:

$$\text{Total capital cost} \begin{cases} \text{Three-phase, \$5,700,000} \\ \text{Single-phase, \$5,000,000} \end{cases}$$

These two figures are for the same quantity of electricity delivered annually to the distributing system in the two cases and not for a given result as regards the quantity of freight or passengers transported.

I have worked through corresponding estimates for a load factor of only 0.25 at the substations and have brought the results of this and of the preceding calculation into the following table:

Load factor at the substations....................		0.50	0.25
" " " " generating station..............		0.50	0.50
Cost at point of delivery	Cont. elec...............	1.25 cents	1.40 cents
	Single-phase elec.........	1.06 "	1.08 "
Per cent greater cost of cont. elec..................		18 per cent	30 per cent
"Annual" efficiency of substation	Cont. elec....................	0.90	0.85
	Single-phase elec..............	0.96	0.95
"Annual" eff. from steam turbines to distribution system	Cont. elec..........	0.81	0.76
	Single-phase elec....	0.81	0.80
Total capital cost	Cont. elec.................	$5,700,000	$6,150,000
	Single-phase elec..........	5,000,000	5,130,000
Percentage greater capital cost in cont. elec. case....		14 per cent	20 per cent

It does not come within the scope of this paper to deal with the relative costs and losses in the distribution system between the substations and the trains, nor with the relative weights, costs and efficiencies of the electrical equipment required on the rolling stock in the two respective systems. These matters have already come in for very thorough discussion on many recent occasions. On these occasions the rolling stock conditions have been dealt with quantitatively and with considerable precision, and, in general, show that the single-phase system requires a very much higher outlay for rolling-stock equipment than is required when the continuous-current system is employed.

But in the matter of the generating and transmitting systems, the assumptions made have often been of a rough character, since it was recognized that the rolling stock was usually the determining factor in the situation. This has led to the prevalence of misleading impressions and it is the mission of this paper to replace these misleading impressions by more reasonable data.

We see from the results that in so far as the train service is of a character permitting of a substation load factor of as high as 0.50, the overall efficiency from the steam turbines to the outgoing cables from the substations is substantially the same for the single-phase as for the three-phase proposition in the typical instance to which the estimates apply, and that even for so low a substation load-factor as 0.25, the overall annual efficiency between steam turbines and distributing system is still only 4 per cent greater in the single-phase system.

In determining upon the appropriate system for any given train service, the single-phase system's (usually) slightly lower capital cost in respect to the sum of the costs of the generating, transmitting and substation outlays, must be studied in comparison with its very much higher capital cost in respect to the rolling stock equipment. The capital cost of the rolling stock equipment is usually very much greater for the single-phase system than for the continuous current system. Obviously with a sparse service of through trains, the single-phase system shows up to less striking disadvantage than for a frequent service of trains making many stops, and extreme cases may arise where the single-phase system should be employed. The data set forth in the table on p. 178 shows the importance of providing a high load factor at the substations. For a given train service, the load factor is higher the greater the distance between substations. It has now been thoroughly demonstrated that high-pressure continuous-current electricity is eminently suitable for the operation of suburban railway trains and that for such a service, it permits of amply great distance between neighboring substations to provide a high load factor. But for freight service and for operating long-distance express trains, the conditions imposed are of a character where single-phase methods do not show up to so great disadvantage when compared with continuous current methods. Nevertheless, the recent developments with high-pressure continuous-current substations have shown that it is appropriate even for very sparse services of freight and express-passenger trains.

Cases, however, may arise where the best plan of procedure will be to employ both systems. In such cases, the freight trains and the express passenger-trains can be hauled by single-phase locomotives while the motive power for suburban passenger-trains can be provided in trains composed of appropriate combinations of motor cars and trailers.

For the estimates where the substation load-factor is 0.50, the make-up of the final cost of the electricity delivered to the distributing system is tabulated below:

	Three-phase proposition	Single-phase proposition
Cost of the electricity when delivered to the step-up transformers	0.783 cent	0.817 cent
Cost associated with the step-up transformers	0.027 "	0.037 "
Cost associated with the transmission line	0.094 "	0.130 "
Cost associated with the substations	0.339 "	0.073 "
Total cost	(1.243 cent) 1.25 "	(1.057 cent) 1.06 "

At this point I am tempted to include mention of the consequences which would result from the development of large static-rectifier sets. It would appear that those of the mercury-arc type will be at least equally small and efficient at high periodicities as at low periodicities. If further developments bear out this indication, then the use of mercury-arc rectifiers in substations as an alternative to synchronous converters will permit (when the periodicity is not fixed by other conditions) of employing periodicities of 60 cycles per second with the associated advantages as regards lower price and higher efficiency of the step-down transformers. On this plan, the transmission would continue to be polyphase. But if, (as some single-phase advocates propose) static rectifiers are placed on the train and employed to supply continuous-current motors, the difficulties relating to the impedance of steel rails would continue to necessitate the use of low periodicities such as 25 or even 15 cycles per second, or else it will be necessary to supply liberal copper feeders tapped off to the rails at frequent intervals.

The indications are that the commercial development of static rectifiers of large capacity will increase the range of appropriate application of the three-phase system with substations and employing continuous-current motors on the trains, or, conversely, and contrary to the usual prediction, will greatly narrow the range where the single-phase system is economically more appropriate. But the chief cause for satisfaction and one which will be shared by all electrical engineers is that any such development of static rectifiers will increase the range or work where electrical methods of operating trains will be economically more appropriate than steam locomotive methods. Judging from the properties of mercury arc rectifiers, large polyphase static rectifiers will be not only more efficient than, but also considerably cheaper than the equivalent synchronous converters, and this together with the probable practicability of employing a periodicity of 60 cycles per second will materially decrease the cost of the electricity required for given train operations.[13]

I am aware that it will be maintained that in my estimates, I have handicapped the single-phase proposition with step-up and step-down transformers. Now it should be pointed out that any really large railway electrification propositions will be associated with transmission at a much higher pressure than will be appropriate for the generators or for the trains. To dispense with step-up and step-down transformers will either unduly increase the cost of the extra-high-pressure generators and of the distribution system, or else it will lead to the use of a system employing some 11,000 volts for generation, transmission and distribution. In this latter case, generating stations will have to be located near the railway line and at comparatively frequent intervals.[14] For the sake of obtaining at the generating station the advantages of a high load factor, it is important to supply from a single generating station as extensive a system as possible, and the accomplishment of this object is defeated by substituting several smaller generating stations of relatively low pressure in order to avoid employing transformers. Such restrictions would be a handicap to large railway electrification work dealing with freight and express-passenger traffic and yet it is for precisely this class of work that the single-phase is economically at a minimum of disadvantage in comparison with the three-phase system with synchronous converter substations.

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[13] Thus in the 0.50 load-factor estimate, the capital outlay for substations accounted for $1,440,000 out of the $5,700,000 aggregate outlay for generating station, transmission line and substations. Cutting the substation outlay in halves reduces the aggregate outlay to $5,000,000, the figure arrived at in the single-phase estimate. The annual efficiency from steam-turbines to the outgoing cables from the substations would become about 84 per cent as against the figure of 81 per cent for the equivalent single-phase proposition.

The primary object of this paper is to indicate methods and supply data of a character to assist in arriving at the economic boundary line between the two leading systems of railway electrification. I wish engineers could realize how satisfactorily the two systems can be worked together when desirable. Conductor rails supplied from synchronous converter substations constitute the means of providing the electricity required by the frequent service of suburban multiple-unit trains. These conductor rails will extend 20, 30, 40, or more miles (32, 48, 64 km.) from the termini in large cities. As the suburbs are built up, the system will be carried out further, the economic limit being readily determined for any particular case. Right from the terminus the overhead contact line can very readily also be provided if it is considered desirable that single-phase locomotives shall haul the freight and express passenger trains when the conditions are such that this traffic can be handled as economically by electrical as by steam-locomotive methods.

The Liverpool-Southport section of the Lancashire and Yorkshire Railway has been operated for the last eight years by the three-phase system with synchronous converter substations. This section comprises 18 miles of route. Mr J. A. F. Aspinwall, the General Manager of this railway, states (see p. 64 of the Minutes of the Proc. of the Inst. of Civil Engrs. for November 1911) that "at Liverpool and at Southport and more particularly at Sandhills Junction, where all the goods-traffic is dealt with, there are more crossings and points and through crossings to the acre than at any other place in the kingdom." The freight traffic is still handled by steam locomotives over the electrically equipped track, only the short-distance passenger traffic being operated from the third rail. After eight years of experience with this line Mr. Aspinwall does not hesitate in expressing at p. 64 of the Proc. of the Inst. of Civil Engrs. for November 1911, in the course of the discussion of a railway electrification paper by an advocate of the exclusive use of the single-phase system, the following opinion: " In another portion of the paper the author said it was quite inconceivable that satisfactory results could be obtained by installing a double system, one to work only short-distance traffic and the other long-distance traffic. With that he did not agree. If the author meant by that the system which is in use on the New York Central in New York, where there were two systems working off a third rail, possibly there were difficulties; but if, on the other hand, it was the right thing to have a single-phase system for long-distance traffic, he could see no difficulty whatever in fitting up the Liverpool Terminus with wires overhead for dealing with long-distance traffic, leaving the third rails where they were for dealing with suburban traffic. The suburban traffic required its own special form of rolling stock, quite different from the stock for long-distance traffic, and the long-distance traffic would be hauled by electric locomotives. There would be no difficulty about the two systems coming into the station, while there would be the advantage that the same superintendents, the same staff, the same generating-station, and the same boilers, with some difference in the machinery, would apply to both. But whether the single-phase system, or the three-phase system, or the direct-current system was the right one to adopt, surely nobody who was responsible for the management of any railway in England would be so foolish as to pin his faith in present circumstances to any one of them. Surely it was not possible that finality had been reached with any one. If there were defects in any system those defects would be put right, and with the rapid changes that were taking place in connection with all electrical machinery, it could not be supposed that a rigid finality in the matter had been reached. Therefore, to say that the best system was any one of those three seemed to him to be wrong."

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[14] The adoption of a definite and relatively low pressure such as 11,000 volts for the entire system will impose serious restrictions on the location of the generating station as regards site, and cost of supplies of coal and water. It will also involve departure from the most economical transmission line, whereas with the freedom secured by employing step-up and step-down transformers, the transmission line can be proportioned in each instance for maximum resultant economy where both capital and operating costs are taken into account.

At present it is with respect to the suburban traffic that the superiority of electrical over steam-locomotive methods is most striking, and for such traffic it is undesirable to handicap electrical propositions by adopting the distinctly less economical means afforded by the single-phase system. This latter system is more in its element for freight service and for express-passenger service although for these classes of traffic, the steam locomotive is usually still the most appropriate at the present stage of development. But in many districts, railways can purchase their electricity from existing electricity supply companies who already have large loads of low power-factor and lagging in phase. In such instances it is of no inconsiderable advantage to the electricity supply companies that the railway load shall lead in phase and thus in a certain measure offset the lagging load of their present supply. This is accomplished with synchronous converter or motor-generator substations. The trains may be few and far between but the synchronous machinery in the substations will exert a decidedly beneficial effect if operated at such over-excitation as to raise the power factor of the system. It has often been considered that unless the trains passed at fairly frequent intervals, the capital outlay for substations and their light-load losses militated severely against electrical propulsion. But in the light of present developments of large power supply companies we see that such synchronous substations serve not only the useful purpose of supplying electricity for the propulsion of trains, but that they also serve a valuable purpose when they are otherwise idle, in that they can be adjusted to improve the power factor of the system. When due consideration is given to this double function, it is evident that supply companies can profit by selling electricity at a very low figure under these conditions. Indeed in view of the advantages to which attention has just been drawn, it is evident that the large power supply company can profit when selling electricity at a decidedly lower price than that at which a railway company could generate it for the exclusive supply of a sparse service of heavy trains, since such exclusive installations would have a very poor load factor and consequently a relatively high capital cost. These considerations, regarding which it is difficult to generalize, tend strongly toward rendering the high-pressure continuous-electricity substation method preferable even for a sparse train service.

Until recently I have been of the opinion that while the three-phase-continuous-current system is out of all proportion the most economical for dealing with a dense service of trains making frequent stops, the other extreme, namely, a sparse service of heavy, through trains, could be at least as efficiently handled by the single-phase system. But the very successful results which are attending the employment of high-pressure-continuous-current and the clearer recognition of the disabilities of the single-phase system at all parts of the proposition and not only in the rolling stock equipment, have served to satisfy me that the three-phase continuous-current system is appropriate for a very wide range of railway work.

As is well-known, it has been stoutly maintained by some engineers that single-phase current is the most suitable for all railway electrification projects, I contend that the continuous-current has much greater claims to be thus designated.[15] The continuous-current system is distinctly more economical than the single-phase system when employed for dense urban and suburban sections of a railway. When all the commercial factors are taken into consideration, it is now realized that it is rarely less economical than the single-phase system even for roads characterized by an exceedingly sparse traffic of heavy freight and express passenger trains. If, therefore the advantages of uniformity should ultimately be found important, then there are the best of reasons that the selected system should be the continuous-current system.

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[15] In the course of the discussion of this subject on a former occasion I have put the matter as follows: (see p. 1289 of Proc. Inst. Mech. Engrs. for 1910) "If when, and wherever the single-phase system is developed to the point of being useful on the main-line railroads, there will be no appreciable difficulties in using it in such cases in conjunction with the use of the continuous-electricity system. It is precisely in this matter of flexibility that electrical methods excel. Almost any desired transformation with respect to the precise *kind* of electricity can be readily effected, and usually at high efficiency and reasonable capital cost. Thus the case for proceeding with a scheme of rigorous standardization is by no means urgent. In so far, however, as there should be any need for standardization, since the most extensive field for electrification is much more economically filled by the continuous than by the single-phase system, the former system is the one which should be standardized."

PROCEEDINGS

of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

SECTION II

Papers, Discussions and Reports

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*A paper to be presented at the Pacific Coast Meeting
of the American Institute of Electrical Engineers,
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OPERATION OF TWO ALTERNATING CURRENT STATIONS THROUGH PARALLEL CIRCUITS, AND THE DISTRIBUTION OF LOAD AND WATT-LESS CURRENTS BETWEEN THEM

BY J. W. WELSH

Two or more alternating current generating stations may be operated in parallel through the medium of several transmission circuits to which the load is independently connected at intermediate points. This method of operation possesses advantages from the power house standpoint as it offers a choice of the units at two stations in carrying the load and therefore provides greater reliability of service and a more flexible and economical distribution of the load.

Some of the difficulties which may be encountered in a situation of this description relate to the effect produced by the individual characteristics of the transmission circuits on the distribution of load and circulating currents between stations.

It is the purpose of this paper to show first, how two alternating-current generators, when running on the same bus, divide the load between them and what proportion of the watt-less current each carries; and then to extend this to the case of two alternating-current stations operating in parallel through the medium of a long transmission line; and finally to consider the case of two stations running in parallel through a number of transmission lines to which the load is independently connected.

When two alternating-current generators are running on the same bus, it is ordinarily stated that the proportion of load carried by each machine is determined by the adjustment of the governor. To make a machine take more load, the governor is adjusted to speed it up. It is also usually stated that the relative amount of wattless current carried by each machine is determined by adjustment of the field rheostats. Raising the induced electromotive force of one machine increases the wattless current supplied by that machine and thus lowers its power factor. These rules apply ordinarily, because the circuit composed of the armatures, leads, and bus bars for two alternating-current generators is invariably one in which the inductive reactance is many times the resistance. The results are very different, however, if the characteristics of this circuit are the reverse of those stated, as may occur when long transmission lines, or cable systems constitute part of the intermediate circuit between units operated in parallel. It is entirely possible for this circuit to have a resistance equal to the inductive reactance or even greater. The possible case in which the capacity reactance of the circuit is great enough to exceed the inductive reactance need not be here considered, since such a circuit would not permit of parallel operation; the fundamental condition of which is that there must be some inductance in circuit.

The simplest explanation of the transfer of both load and wattless current from one unit to another is to assume the existence of a cross current flowing only in the circuit between units and including the machine windings. Assuming all other conditions the same, each unit generates a current equal in all respects to the other. This cross current combines with the current of each machine giving a resultant current which is registered on the machine meters. The important fact in connection with this cross current is that under certain circumstances it transfers a wattless current from one unit to the other; and under certain other circumstances it transfers load from one unit to the other.

While this matter can best be understood by a reference to vector diagrams, as shown in Figs. 1 to 5, it may be explained somewhat as follows:

When two alternating-current units are operating in parallel, their induced electromotive forces are opposing each other, and if they are equal in magnitude and in exact opposition, the output of the two units must be equal both in the energy and the wattless components of the current. These electromotive forces, however, since they are the induced electromotive forces, may be unequal without in any way disturbing the bus bar voltage, assuming the two units operating on the same bus. One electromotive force may be greater in magnitude as a result of the relative field adjustment of the two units. and one electromotive force may have an angular advance ahead of its true position of opposition to the other, when, as a result of governor adjustment, one machine tries to speed up. In either case, a resultant electromotive force occurs, equal to the geometric difference between the two machine electromotive forces, the effect of which is to set up a cross current in the circuit composed of the two armatures, cables, and bus bars. In the first case, when one electromotive force is greater in magnitude than the other, the resultant electromotive force is in phase with the greater of the two electromotive forces. In the other case, where one electromotive force leads its position of opposition, the resultant electromotive force is half way between the machine electromotive forces and approximately at right angles to them.

The resultant electromotive force, whatever its phase position, sets up a cross current which in turn will lag to a greater or less amount behind the resultant electromotive force, depending on the characteristics of the circuit. If the circuit consists principally of inductive reactance, as in the case of generators operating on the same bus, the cross current will lag behind the resultant electromotive force by approximately 90 deg. If the circuit consists largely of resistance, the cross current will be more nearly in phase with the resultant electromotive force. The magnitude of the cross current depends on the magnitude of the resultant voltage and is inversely porportional to the resistance and reactance of the circuit.

From the above considerations, it appears that the question of whether load or wattless current is transferred from one machine to another is dependent on the phase relation of the cross current to the equal machine currents. Assuming 100 per cent power factor for these machine currents, if the cross current is brought into phase with the current of one machine and therefore approximately into opposition with the current of the other machine, it is added to the current of the first machine and substracted from the second, so that there is a transfer of load between the machines. If the cross current lays halfway between the current of the two machines, it neither adds to or subtracts from the load of either machine, but it combines with the current of one machine, increasing its lag and wattless current and at the same time combines with the current of the other machine, decreasing its lag and wattless current.

These conclusions may be summarized more exactly as follows: With the cross circuit made up of both resistance and reactance, field adjustment causes a transfer of load proportional to the resistance component of the cross current and governor adjustment causes a transfer of load proportional to the reactance component. Wattless current is transferred by field adjustment in proportion to the reactance component of the cross current; and by governor adjustment in proportion to the resistance component.

A summary of the results for all cases is given herewith, with a reference to the vector diagrams: These vectors show relative values only, and do not represent the absolute magnitude or phase of any quantities. It should be noted here that the term "governor adjustment" is used in the sense of phase displacement of the machine voltages. Considering all conditions equal, the effect of governor adjustment is to change the phase angle. Such change in the setting of the governor as may be necessary to supply the driving power for the load on a machine, but which does not involve a displacement in the machine voltages, is not taken into account, since this action is considered as secondary. Similarly the expression "field adjustment" is used to denote changing the relative magnitude of the induced voltage of the machines. Any field adjustment that is necessary to maintain the same relative voltage when a change of load occurs due to the change in demagnetizing action of the armature on the field, is not taken into account, since this action is also regarded as secondary.

Case 1.—*Two machines carrying equal load on same bus. Machine circuit, principally inductive reactance. Power factor of load, approximately* 100.

Figure 1 shows the effect of field adjustment. Raising the induced electromotive force E_1 of one machine gives a resultant voltage E_0 in phase with E_1 and sets up a cross current I_0 lagging about ninety degrees from E_0. The current I_0 combines with the equal load currents I from each machine, giving the actual current I_1 from one machine and I_2 from the other machine. This is a transfer of wattless current principally.

The bus bar voltage is not shown to avoid confusing the diagram. It can be found by deducting geometrically the impedance drop from the induced electromotive force of either machine.

Figure 2 shows the effect of governor adjustment. Speeding up one machine advances the induced electromotive force of that machine, giving a resultant voltage E_0 half way between the induced electromotive forces of the two machines. The cross current I_0 lagging approximately ninety degrees behind E_0 is approximately in phase with the load current I of one machine and in opposition with the load current of the other machine. This results in a transfer of load from one machine to the other, as shown by the actual currents I_1 and I_2.

In either of the cases, the actual amount of load or wattless current transferred is the same regardless of the power factor of the load.

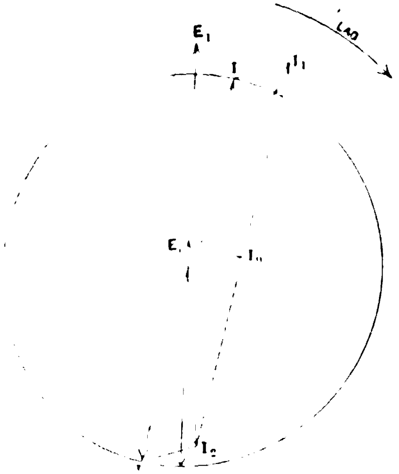

FIG. 1.—TWO A-C. MACHINES ON THE SAME BUS

Machine circuit is principally made up of inductance. Power factor of load approximately shows effect of raising voltage E by field adjustment

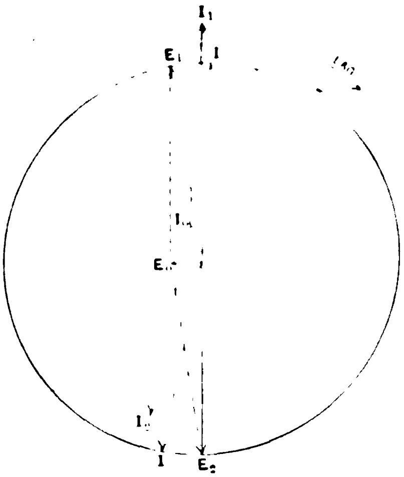

FIG. 2.—SAME AS FIG. 1, EXCEPT VOLTAGE E IS ADVANCED BY GOVERNOR ADJUSTMENT ONLY

Case 2.—*Two alternating current stations connected to a long transmission line and carrying equal load. Circuit between stations, principally resistance. Power factor of load, approximately* 100.

Figure 3 shows the effect of field adjustment. Raising the station voltage E_1 gives the resultant voltage E_0 in phase with E_1 and sets up the cross current I_0 between stations and approximately in phase with E_0. I_0 combines with the equal load currents I, thereby transferring load as shown by actual currents I_1 and I_2. This illustrates how load may be transferred from one station to another by field adjustment, there being no phase displacement of the station voltages.

Figure 4 shows the effect of governor adjustment. Speeding up one machine gives the resultant voltage E_0 halfway between E_1 and E_2 and sets up the cross current I_0 approximately in phase with E_0 and ninety degrees in phase from the load currents I of the two stations. The principal effect of this cross current is to transfer wattless current from one station to the other,

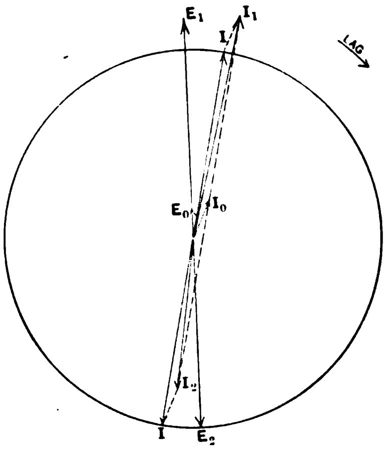

Fig. 3.—Two A-C. Stations Connected to a Long Transmission

Circuit between stations principally resistance. Power factor of load approximately 100. Shows effect of raising voltage E by field adjustment

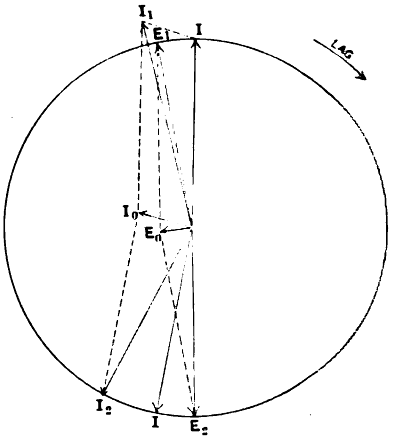

Fig. 4.—Same as Fig. 3 Except Voltage E is Advanced by Governor Adjustment Only

thereby reducing the lag angle of the load at one station and increasing it at the other. There must also be a certain transfer of load between stations which will be proportional to the reactive component of the cross current, and must be just sufficient to equal the change in power supplied by the change in governor adjustment. This determines the amount of inductive reactance necessary for parallel operation.

The same changes which are secured between the induced electromotive force and the bus bar voltage by either field or governor adjustment as shown above are also produced by the impedance drop in voltage from the bus bar to the point of load connection between two stations connected by a transmission line. Assuming for simplicity one hundred per cent power factor, the resistance drop, since it is in phase with both the current and the bus bar voltage corresponds to a reduction in voltage by field adjustment. Similarly, the inductive drop, due to the reactance of the line, lags ninety degrees behind the bus bar voltage and therefore corresponds to a slowing down in speed by governor adjustment.

The part played by the resistance and inductance of the line on the voltage is therefore a twofold one, the former reducing it in magnitude and the latter causing a shifting of its position in the direction of lag, similar to the effect produced by a slowing down in speed. These two factors determine the proportion of load pulled from each of two stations when the load is connected at some intermediate point on the line between them. If the line has uniform characteristics between stations and the bus bar voltages at the two stations are equal in magnitude and phase the load will be divided between the two stations inversely as the distances between the point of load connection and each station. This follows from the fact that the drop in voltage must be the same from the equal bus bar voltages at each station to the load whatever the relative location of the load on the line may be. Moreover, since the voltage drop is the product of the line impedance and the current, the less the impedance (due to shorter distance) the greater the current. This can be seen by referring to Figure 6, where the line drops from each station are represented respectively by $I_1 Z_1$ and $I_2 Z_2$; the vectors $I_1 R_1$ and $I_2 R_2$ represent the resistance drops and the vectors $I_1 X_1$ and $I_2 X_2$ the drops due to inductive reactance.

By subtracting vectorially, the drops $I_1 Z_1$ and $I_2 Z_2$ respectively from E_1 and E_2 the voltage E_{L1} is found, and it must be equal to E_{L2} since these represent the one voltage at the point of load connection. The load currents I_1 and I_2 are shown as equal, but they may or may not be equal, depending upon whether the impedances Z_1 and Z_2 are equal.

From the above, it may be concluded that by a proper proportioning of the voltage of each unit, either by field or governor adjustment, it is possible to secure any desired sharing of the load and of the wattless current between units, whether running on the same bus or at opposite ends of one transmission line. It should be noted, however, that there are usually limitations to any great change in voltage either by field or governor adjustment, due not only to the necessity of keeping within the rating and capacity of the machines, but also to the requirements of a lighting load where a fixed voltage is necessary.

A new condition arises when more than one circuit is connected between stations operating in parallel. So long as the bus bar voltages at the two stations are equal in all respects, there is no unbalanced voltage acting on the system and the situation does not differ from that of one connecting circuit between stations. When, however, by field or governor adjustment one station is made to carry more load than the other there is a resultant unbalance voltage acting on all of the connecting circuits between stations and setting up cross currents therein. If all of these circuits have the same characteristics, as regards resistance and inductance and if the power factor of the load on each circuit is the same, the cross current in each circuit will bear the same relation to the load current of each circuit so that just as in the case of a single connecting circuit, suitable adjustments of relative station voltages may be made to bring the

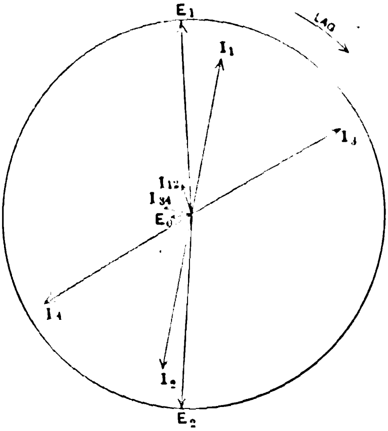

FIG. 5.—TWO PARALLEL CIRCUITS FED AT EACH END BY A-C. GENERATING STATIONS

One circuit consists principally of resistance; and one of reactance. Power factor of load different on each circuit. Shows how impossible to limit all wattless current

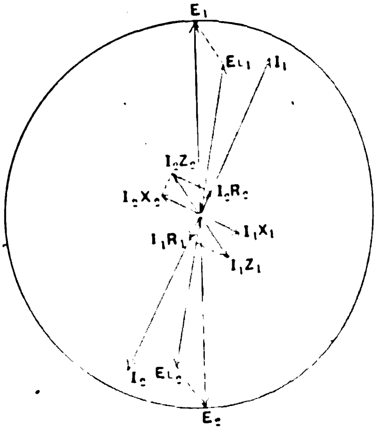

FIG. 6.—SHOWS EFFECT OF RESISTANCE AND REACTANCE OF LINE ON STATION VOLTAGE RECEIVED AT LOAD CONNECTION

cross current of each circuit into the desired relation to the load current of that circuit.

If, however, either of the above circuits have different characteristics as regards resistance and reactance or if the power factor of the load on each circuit is different, then the cross current will be different for each circuit. It may be made to coincide with the load current of one circuit, but obviously cannot simultaneously be made to coincide in all circuits. The result is that an additional wattless circulating current is imposed on certain connecting circuits of the system. This wattless current will lower the power factor at one station and raise it at the other, but its effect in either case is in addition to the wattless current, due to the power factor of the load which is carried at each station. This is shown in figure 5 where the resultant electromotive force E_0 sets up the cross current I_{12} on one circuit, carrying the currents I_1 and I_2 respectively from each station; and it also sets up the cross current I_{34} in the circuit having the currents I_3 and I_4 respectively. It is evident that by voltage adjustment E_0 can be shifted to bring I_{12} to coincide with I_1 and I_2, but this will simultaneously cause I_{34} to shift further out of phase from I_3 and I_4. The cross current I_{34} therefore introduces an additional wattless component of the current into the system. It will be seen that any shifting which will bring the cross current of one circuit into coincidence with the load currents of that circuit will shift the cross current of the other circuit further out of phase.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16-20, 1912.

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AIR GAP FLUX DISTRIBUTION IN DIRECT-CURRENT MACHINES

BY CHARLES R. MOORE

The armature of a direct-current machine under load reacts on the main field, the effect being commonly known as armature reaction. This reaction always has a tendency to distort the main field and may increase or decrease the total flux per pole, depending on the brush position and the relative values of armature and field strength. The distribution of the flux, then, along the air gap of a direct current machine is different, when the armature conductors carry current of appreciable strength, from what it is when the machine is running light. The extent of this change in air gap flux distribution determines largely the success of the design, so that it is highly important to be able to determine if possible what the flux distribution will be under load; in fact, no scheme of design can be regarded as complete unless it enables the designer to predetermine with reasonable accuracy the full load as well as the no-load characteristics of a given machine.

As carried out at the present time direct-current machine design points out the no-load characteristics only, the full load characteristics being arrived at by the use of certain constants, applicable to the type and capacity of the machine in question. These constants being derived from experience give results sufficiently close for practical cases, but when designs of radical types are attempted the full load characteristics are more or less a matter of conjecture, and the machine must be designed with sufficient liberality to be safe.

The writer believes that this full load condition should be capable of development from fundamental physics rather than from empirical formulas and the experiments herein described were carried out with this in mind. The general plan of the work has been to study one machine thoroughly rather than to collect an array of data from many machines.

This paper has for its object a description of these experiments together with a discussion of the method developed by means of which the full load flux distribution of a direct-current machine may be easily and accurately predetermined from design data. The work herein described pertains to generators, but the method is applicable to motors as well.

TESTS

The experimental apparatus consisted in general of a four-pole direct-current machine, having an exploring coil, similar in shape to one of the regular coils, mounted on the armature and connected to two slip rings through which connection could be made to an oscillograph; also such auxiliary apparatus as was necessary to define accurately the conditions obtaining when a film was exposed. The exploring coil had a throw equal to a pole pitch, and was mounted on the surface of the armature by cutting a small groove in one of the retaining wedges and soldering clips to the teeth on either side after the coil was laid in place. The ends of the coil were held down by clips soldered to the binding wires.

It is obvious that, as this coil passed along the air gap at uniform speed, it would have electromotive forces induced in it proportional to the flux cut, and since the spread was inappreciable the curve shown by the oscillograph could be taken as that of flux distribution. In addition to the general shape, the curve secured showed harmonics, giving a notched appearance shown in Fig. 9 due to the pulsating reluctance of the magnetic circuit, as the number of teeth under a pole varied from maximum to minimum. This point will be brought out more fully later. The coil used was made up of four turns of No. 24 double cotton-covered magnet wire. The machine on which this coil was mounted was in reality a converter and is shown in Fig 1. This machine was of the type A.C.S., four-poles, 7.5 kw. running at 1800 rev. per min. The data on Plate III pertains to this machine.

This machine was one of two similar machines mounted on the same foundation, the two being so arranged that their shafts might be coupled together directly. This afforded an excellent drive as the motor could be run as a synchronous machine giving

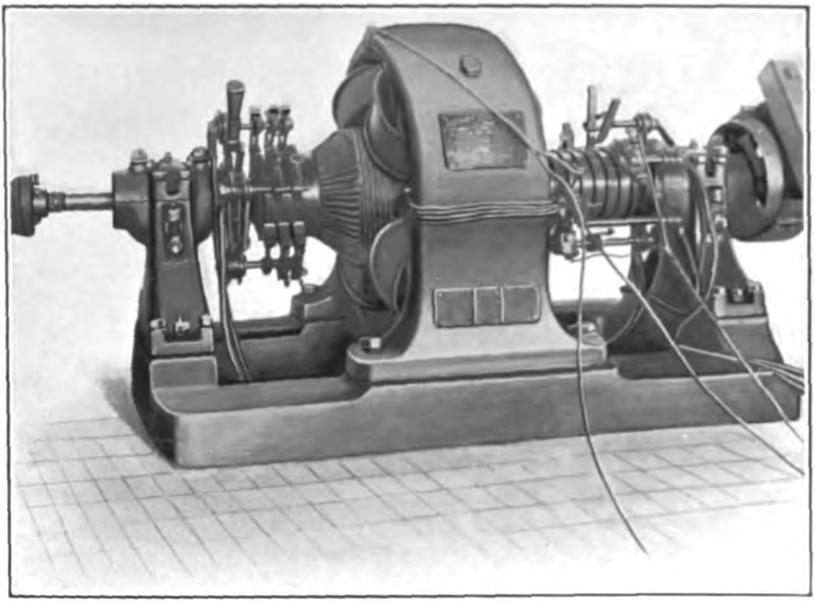

FIG. 1 [MOORE]

MACHINE DATA

Armature Winding:	
Type	Lap
Number of circuits	4
Number of coils	96
Turns per coil	3
Number of armature slots	48
Number of commutator segments	96
Number of armature conductors	576
Field Coils:	
Type	Shunt
Number of turns per coil	1725
Number of coils	4

Length of air gap, $\frac{1}{8}$ inch (3.17 mm.).

practically constant speed. In addition to this advantage the synchronous motor on the oscillograph could be run from the same source as the machines being tested, and since this small motor had four poles also, it was in synchronism with the alternating electromotive forces generated in the test coil on the experimental machine. By this arrangement it was unnecessary to take current from the test coil except just enough to operate the oscillograph galvanometer. The tests were run at times when the load on the power station was light or constant so that practically constant speed was assured. A tachometer was used, however, as a check.

As anticipated, the flux distribution curve shifted position along the ground line in the direction of rotation when load was put on the generator so that, in order to have some reference point whereby this shift could be measured, a contactor was mounted on the shaft and connected in series with a battery and one of the galvanometers of the oscillograph. Once each revolution of the test machine, this galvanometer threw on the screen a "kick" which was permanent in position regardless of the flux shift. The brush of this contacting device was placed on a rocker arm so that the position of the "kick" could be set at will. The position chosen was the point of zero flux or when the flux curve crossed the ground line at zero load. When load was put on, the shift could be measured directly.

It was also found necessary to have some device for accurately locating the brush position on the films. This requirement was met by placing a second contactor on the shaft close to the commutator and mounting the brush which engaged with it on the rocker-arm to which the regular brushes were attached, so that, as the brushes were shifted, the "kick" shown by the galvanometer to which this contactor was connected moved therewith.

The neutral points on the commutator were located by substituting for one of the regular carbon brushes a wooden brush on the opposite faces of which, in the direction of rotation, were fastened two pieces of strip copper; these bore on the commutator surface, spanning about three segments, and to them was attached a voltmeter. With the machine running light the rocker arm was set with the brushes on the neutral point. The contactor brush was then so adjusted on the stud that the "kick" shown by the galvanometer due to it, coincided with the point where the flux curve crossed the ground line. To set the brushes at the neutral point, with the machine loaded, it was only necessary to shift the rocker arm until the "kick" again coincided with the point of zero flux.

The oscillograph was of the galvanometer type having three cells. After each film was exposed a calibration line was drawn upon it by impressing on the galvanometer with which the curve was taken a known voltage from battery. Before exposure, the light from all three galvanometers was concentrated on a single spot.

In order to get several curves on a single film, the zero point or point of concentration of the spots of light was moved to one side slightly after each exposure.

Fig. 2 shows the connections used for these tests. The field of the generator as well as that of the oscillograph was excited from a storage battery to insure constant conditions.

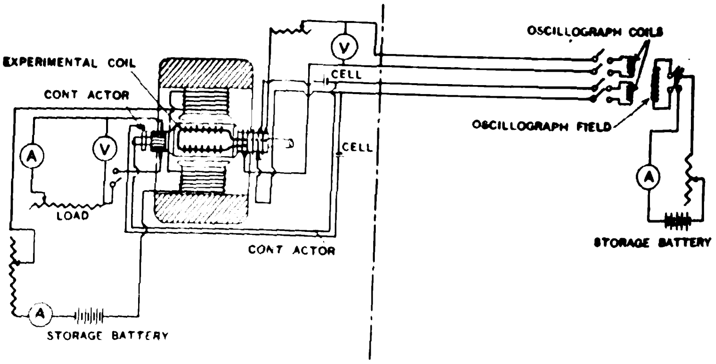

Fig. 2.—Diagram of Circuit

Theory

Before discussing data and results it will be necessary to explain the theory followed in working them out.

Prof. Goldsborough has read before the Institute* papers dealings with flux distribution in air gaps and armature cores but nothing has been found in his researches relating to flux distribution in the air gap under load conditions. In the first of his papers he explains the application of the theory of reciprocals, but at that time no oscillograph was available and he found it necessary to check his work by means of commutator exploration. Everyone knows the dangers lurking in the use of exploring or pilot brushes, so far as quantitative values are concerned, so that it was first necessary to re-check Goldsborough's methods and then to develop a theory applicable to the load condition.

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* See Series of papers, Transactions A.I.E.E., Vol. 15, p. 515; Vol. 16 p. 461 and Vol. 17, p. 679.

A brief review of Prof. Goldsborough's method as far as we were able to use it will be given. On the pole, as shown in Fig. 3, a series of equally spaced points is laid off and corresponding points are taken on the armature. If the sum of the reciprocals of the distances from any point on the armature to all points on the pole be plotted above the armature point considered, a curve similar to curve *A*, Fig. 4, will be secured. In the first of his

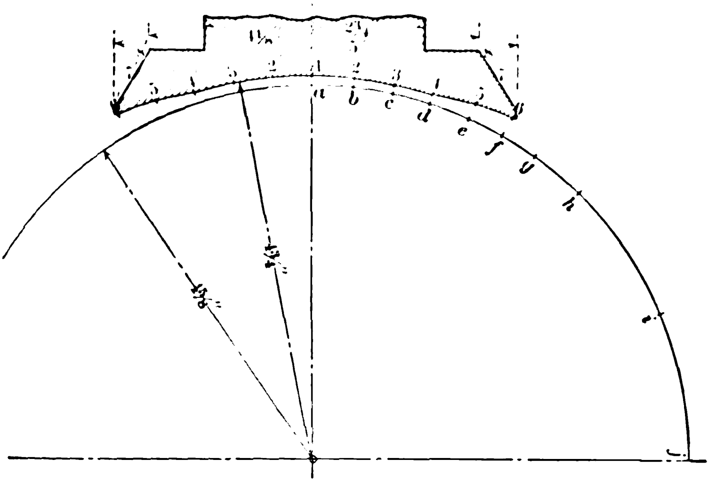

Fig. 3.—Layout of Armature and Pole for Obtaining Theoretical Curves

papers above referred to, Prof. Goldsborough gives mathematical methods for calculating the ordinates for this curve, but the writer's experience indicates that so far as time is concerned there is little to be gained in the use of the equations given. Since the pole shoe and armature are symmetrical with respect to the polar axis it is necessary to take armature points on one side only, as shown in Fig. 3. The table of reciprocals is therefore short and the summations may be easily made.

Just here it might be remarked that in the finding of curve *A*, the pole shoe is regarded as an equipotential plane for all points on the pole shoe and the sides of the pole core as of a varying potential for all points that occur beneath the field coil. This automatically takes care of the effect of the field coil itself on flux distribution, for all load conditions. Prof. Goldsborough preferred to call curve *A* a curve of flux distribution when pole *N* was considered as acting alone.

It is obvious that the poles *S* on either side have similar curves but of opposite sign to that of *N* and if these be plotted in their relative positions and added to *A*, algebraically, a curve similar to A_2 results. Prof. Goldsborough, however, considered one pole pitch only, although there seems to be no reason for not considering the entire number of poles a given machine may

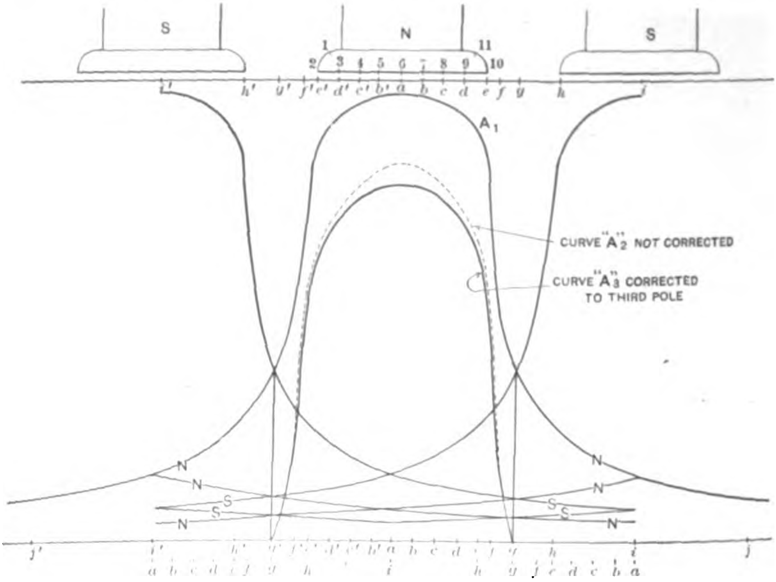

FIG. 4

have. Doing so, however, leads to complication. In Fig. 4 the extremities of curves *A*, etc., are shown for four pole pitches with their algebraic sum A_3.

A better scheme seems to be to consider A_1 as a curve of permeance rather than a curve of flux distribution, since so doing permits one to multiply its ordinates by the values of magnetomotive force acting at the lower extremity, (at the armature points, and these magnetomotive forces may be calculated) thus obtaining a true flux distribution curve.

In order to get a scale for curve *A*, it is necessary to find some point in the air gap where the magnetic lines of force are parallel.

This point is obviously the mid-position along the pole shoe. Knowing the air gap length at this point the reluctance per square centimeter may be calculated, the reciprocal of which may be set equal to the maximum ordinate of the permeance curve and a scale found therefor.

The magnetomotive forces due to the field coils only acting at the various armature points, may be found as follows: Taking the magnetic potential drop along the armature surface between the pole tips as a linear function, (and this assumption is borne out by the tests,) we may represent the magnetomotive forces of two poles relative to the armature as shown in Fig. 5. When no disturbing effects are present on the armature the magnetomotive force acting on the mid point between the pole tips is zero.

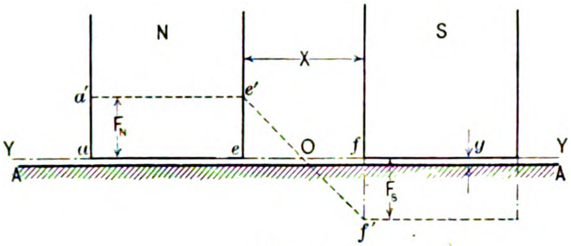

FIG. 5

The magnetic effects of the armature under load may be shown by Fig. 6 as a linear function, having zero value at the middle of the pole shoe and maximum value at a point midway between the poles. Combining these two effects as shown in Fig. 7, the resultant magnetomotive force distribution along the armature surface may be found. Having now the magnetomotive forces acting at the various armature points and the permeance from each point to the pole, it is possible to calculate the flux entering the armature at any given point.

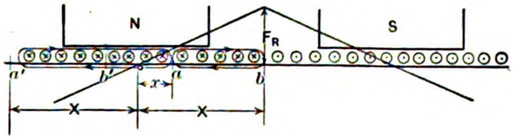

FIG. 6

One other consideration, however, must be taken into account, namely, the reluctance of the teeth, before the real value of flux at a given armature point can be found. This matter, while it may seem complicated at first, may be done without great trouble as follows:

In Fig. 8 is shown the magnetization curve for the teeth and slots considered as parallel magnetic paths. This curve may be worked out in various ways, but the writer has used in this development a common formula due to Messrs. Parshall and Hobart, which is

$$\mathfrak{B}_a = \frac{\mathfrak{B}_t\,(w_s + w_t - w_t f + w_t f \mu)}{w_t f \mu}$$

where $\mathfrak{B}_a$ = apparent density at middle of tooth.
$\mathfrak{B}_t$ = actual density at middle of tooth.
W_s = width of slot.
W_t = mean width of tooth.
μ = permeability of tooth at density $\mathfrak{B}_t$.
f = per cent of armature length that is iron.

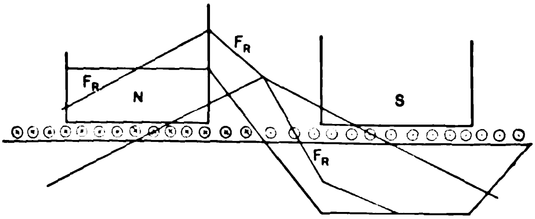

Fig. 7

This formula gives the relation between apparent and actual tooth density so that by assuming various values of $\mathfrak{B}_t$ data for a curve may be worked out from which the actual tooth density may be read when the apparent density is known. The necessary ampere turns for the teeth are then readily calculated.

The straight lines shown in Fig. 8 follow from the value of permeance, for a given armature point, previously explained, the paths being all air paths. Combining now the curve for teeth and slots with the straight lines a curve of magnetization for each armature point may be found, from which the flux entering that point may be obtained when the magnetomotive force is known. Getting, then, the values of magnetomotive force from the resultant curve as given in Fig. 7, the true values of flux entering all armature points taken may be found.

Data and Results

The first effects studied were the shift of field with load, and the effect of field strength on flux position. To this end the curves of Fig. 9, Plate IV, were taken, of which A is the no-load curve, B the full load flux curve but with field excitation the same as for A, and C the full load curve after the field strength had been increased until the total flux per pole was about the same as that shown by curve A. It should be noted that the areas of these curves may be taken as proportional to the total useful flux per pole, so that the decrease in developed voltage as load is thrown on when the field excitation remains constant may be easily studied. Curves given by the oscillograph, however, are usually rather small for quantitative results, but by working carefully a very good idea of the effects present may be secured. It will be noted further that curve A has a notched appearance. That these notches are due to pulsating reluctance of the magnetic circuit may be clearly shown by noting that there are twelve slots per pole and that the frequency of the notches is 24 times that of the fundamental. Furthermore, the notches appear in exactly the same way when the brushes are lifted clear of the commutator and no current whatever is taken from the armature winding.

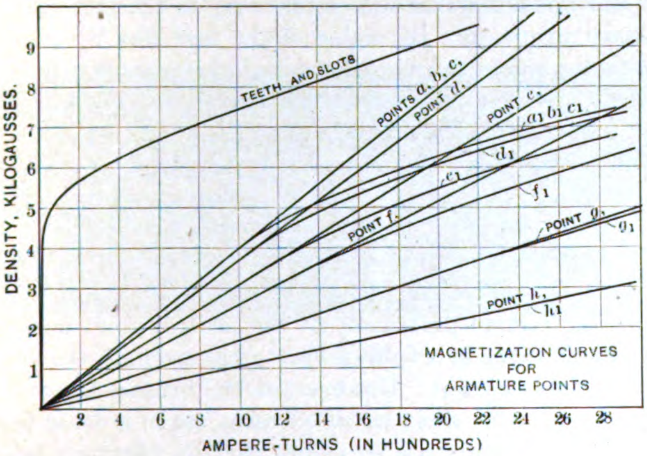

Fig. 8

The extent of the shift can be measured by noting the distance from the contactor deflection to the curve when it crosses the ground line. The ground lines shown in Fig. 9 are not in their true position, and this fact must be taken into account in calculating the shift. Careful measurements taken from Fig 9 show the flux shift to be about 9.5 per cent of the pole pitch in the direction of rotation.

Curve *C* shifted less than curve *B*, showing that the effect of increasing the field excitation with a given armature current flowing is to partially restore the flux curve to its original position. This readjustment comes about from the fact that the reluctance of the teeth under the trailing pole tip increases with flux density faster than the reluctance of those under the leading tip.

The effort made to get the areas of test curves *A* and *C* the same was not altogether successful owing to the fact that it was necessary to measure the value of the field flux by connecting a voltmeter across the slip rings to which the exploring coil was attached. It is obvious that the effective values of voltage, which are proportional to the r.m.s. of the flux curves, are not the same for equal areas on account of changes in shape of the flux curves. The areas secured, however, were sufficiently accurate for the purpose.

The effect of commutation and brush position on the main field was next studied and is shown in Fig. 10, Plate IV. So long as the brushes remain practically at the neutral point and do not short circuit turns in a field of very great strength the effect on the main field is slight. However, as the brushes are moved to positions where the short circuited turns are in a dense field the short circuit currents rise to values that do affect considerably the main field strength. In Fig. 10, the curves are designated the same as in Fig. 9. It will be noted that as the exploring coil passes the brush position, *i.e.*, the coil in the slot beneath it undergoes commutation, the effect of the short circuit flux is clearly shown by the increased height of the points. The writer is at present making an experimental study of reactance voltage of the commutated coil, using as a basis the difference in height of the points as illustrated.

It was very interesting to watch the movement of the notches as the brushes were shifted from the neutral position. At the exact neutral these notches or points were about the same in height when the armature was loaded as when running light. However, the magnitude of the short circuited current increased with change in brush position regardless of the direction of shift,

PLATE IV
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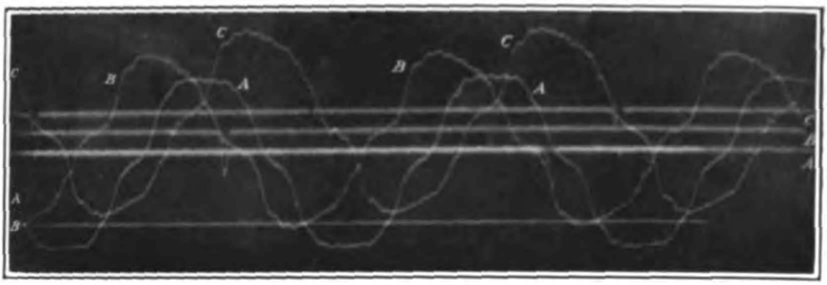

FIG. 9 [MOORE]

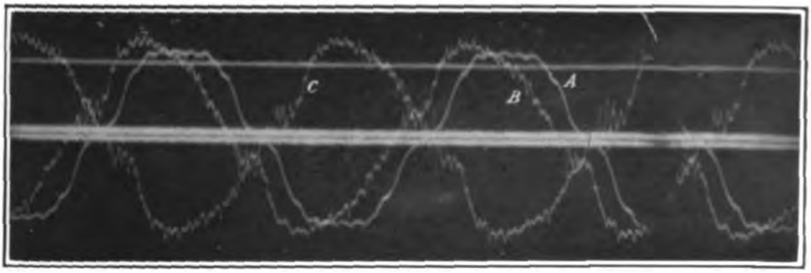

FIG. 10 [MOORE]

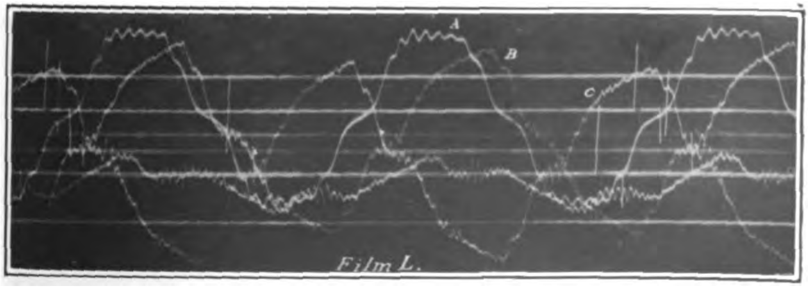

FIG. 14 [MOORE]

and since the coil was in the best position for action on the field, the height of the notches increased. As the pulsations due to varying reluctance coincided with the effects of the short circuited coil the notches increased greatly in height. When these actions were opposed, the notches were very much reduced. The frequency with which a commutator bar left a brush was just double the frequency of the pulsations of reluctance, and the combined effect is clearly shown on some of the films by a large and small notch alternately placed. By neutral point is meant the real position of zero magnetomotive force on the armature and not the no-load neutral. This is explained more fully in the appendix.

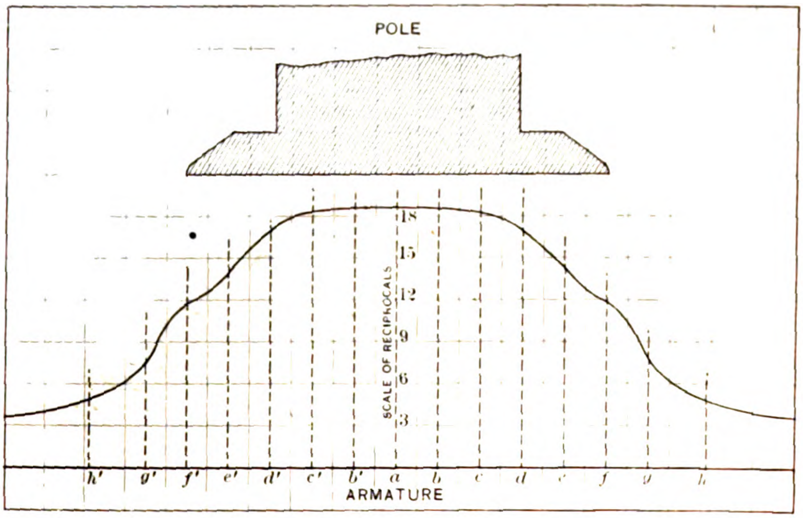

FIG. 11

The most important considerations with which this investigation has to deal pertain to the shape of the flux curves and the derivation of a scale therefor. In comparing calculated with experimental curves, relative to shape, the areas and pitches were made equal so that a common value of total flux was represented by them. Fig. 11 shows the permeance curve for one pole of the test machine. This curve was derived by the method of reciprocals, the points on the pole shoe and armature surfaces being laid off as shown in Fig. 3.

Having the permeance curve which has to do with the ability of a given magnetomotive force to send flux from any armature point to the pole as a whole, or vice versa, and the magnetization curve for the teeth and slots, magnetization curves may be derived for all armature points. In Fig. 8, the straight lines show the relation between density and ampere turns for the various armature points, so far as the air path only is concerned. The slopes of these lines marked *a*, *b*, *c*, was determined by the air gap length at the middle of the pole face. The slopes of the other straight lines were determined by taking the slope of the first line as equal to the maximum value of the permeance curve and calculating a scale by means of which the direction of the lines corresponding to the various armature points could be calculated.

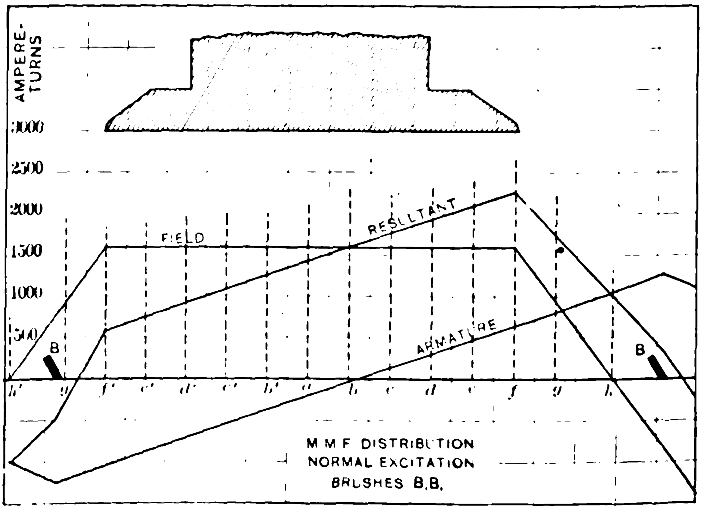

FIG. 12

By combining the teeth and slots curve with these straight lines the real magnetization curves for all armature points could be found. These resultant curves are also shown in Fig. 8.

Fig. 12, shows the distribution of the pole and armature magnetomotive forces under normal excitation and load together with their resultant. By taking values of magnetomotive forces for the various armature points, using the field magnetomotive force distribution curve only, and reading the corresponding densities from the proper curves in Fig. 8, the no-load flux distribution curve results as shown by curve *C* in Fig. 13. By choosing magnetomotive force values from the resultant magnetomotive force curve in Fig. 12, and again reading the densities from the proper magnetization curves in Fig. 8, curve C_1, Fig. 13, results, which is the full load flux distribution curve, the field excitation remaining constant. The dotted curves in Fig. 13 represent the actual flux distribution along the armature surface for the no load and full load condition.

These curves agree so closely that in order to be sure of the method similar curves were worked out for low excitations, and correspondingly low armature load. To this end the curves of Fig. 14, Plate IV, were taken, the field excitation being slightly less than 300 ampere-turns per pole. For the sake of clearness these curves have been traced as shown in Fig. 15 and the ground lines put in their proper positions.

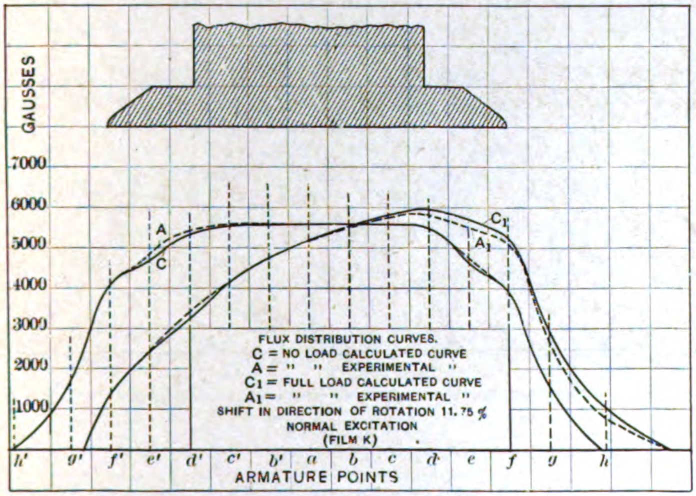

FIG. 13

Figure 16 shows the armature and field magnetomotive force distribution and Fig. 17 shows the no-load and full load flux distribution curves. It will be noted that the experimental curves follow the calculated curves about as closely as is the case in Fig. 13, showing that the method takes into account properly the effect of tooth reluctance.

It should be further pointed out that the maximum flux density in the case of normal excitation, Fig. 13, does not rise much above the no-load maximum values, showing that the teeth are well saturated. With low excitation this difference is greater.

The notches in the actual flux curves have been omitted for the sake of clearness since they in no way affect the general shape.

At the bottom of Fig. 15, is shown a curve of flux distribution caused by the armature current acting alone, *i.e.*, the field current zero and the armature currents forced through by an external voltage. Since this curve has little practical value no attempt was made to derive a calculated curve to check it.

As previously pointed out, the areas of the curves *A*, *B* and *C* are proportional to the developed voltages, so that in a given design the drop in voltage due to reduction of flux caused by armature reaction, may be found and compensated for by adding sufficient excitation to the field to bring the area of curve *C* up to that value which indicates sufficient flux to overcome the armature and brush resistance drop plus the developed voltage at no-load. This may be done by finding first the average air gap densities as given by curves *A* and *B*, and noting the values of field ampere turns given by them on the magnetization curve for the air gap, teeth and slots. This difference is the number of ampere turns per pole equivalent to armature reaction and this value must be added directly to the field excitation to compensate for armature effects. The armature and brush resistance drops may be computed and added to the no-load voltage and an average air gap flux density calculated to give the full load developed voltage. The ampere turns necessary to produce this increase may be found in the ordinary manner.

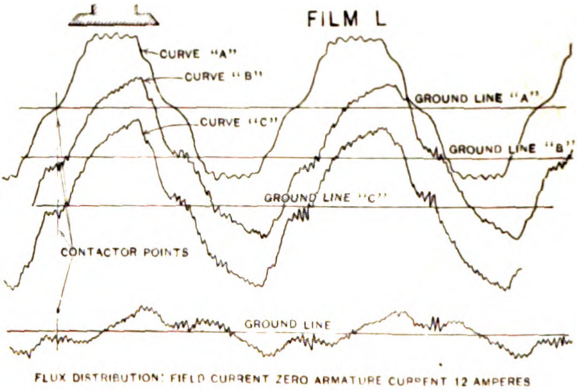

FIG. 15

With the full load field excitation thus determined, curve *C* may be worked out, which will be the true flux distribution curve along the armature surface when the machine is fully loaded and all the effects producing internal loss of voltage are compensated for.

One of the points of interest to the student and engineer, resulting from having the load flux distribution curves, relates to brush position. Having the inductance of the commutated coil, Dr. Steinmetz, in his *Elements of Electrical Engineering*, has already pointed out methods for calculating the proper density in which the coil should move in order to exactly reverse the current, so that by locating this value on the curve near the leading pole tip the brush position may be determined.

It is obvious that since the brush position affects somewhat the shape of the load curves the position just found will be slightly in error, but experiment shows that for a reasonable shift of the brush position the areas under the load curves are not materially altered. In cases where the brush shift must be excessive it is a simple matter to derive a second full load curve taking into account the new brush position.

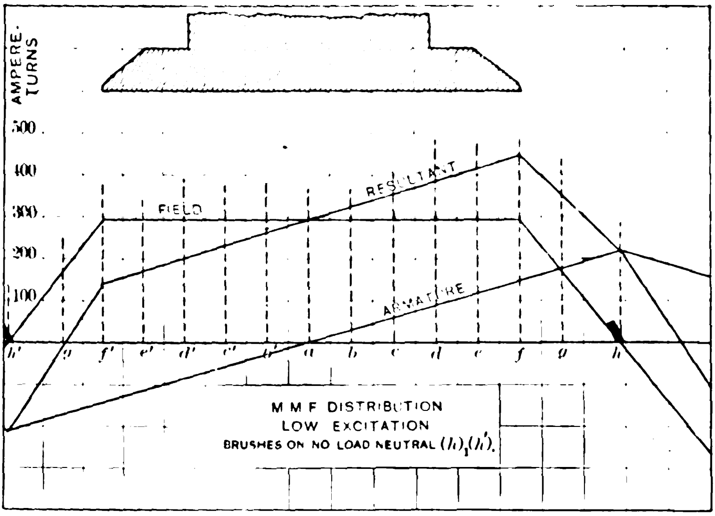

FIG. 16

CONCLUSION

The conclusions to be derived from the above are:

a. The flux distribution curves for any load may be obtained with an accuracy approaching closely experimental observations.

b. The positions of these flux curves are affected but little by brush position when the brush remains near the neutral point.

c. Field ampere-turns needed for overcoming the armature reactions may be calculated without any special reference to cross magnetization or demagnetization in the sense given in standard texts.

d. The brush position may be found accurately from design data.

Appendix

In the course of these experiments and studies several points of interest not pertaining to the final result came up. The first of these relates to the getting of a $\mathcal{B}$-H curve for the armature iron of the test machine. The manufacturers were unable to supply an accurate curve for this machine. Furthermore, it was impossible to separate from the magnetization curve of the entire magnetic circuit, that part having to do with the armature iron only. Fortunately, however, the armature was constructed with two air ducts equally spaced so that by sending a large current through the shaft and threading a coil which was connected to a ballistic galvanometer through the air ducts and around the middle section of the armature iron a satisfactory $\mathcal{B}$-H curve was secured.

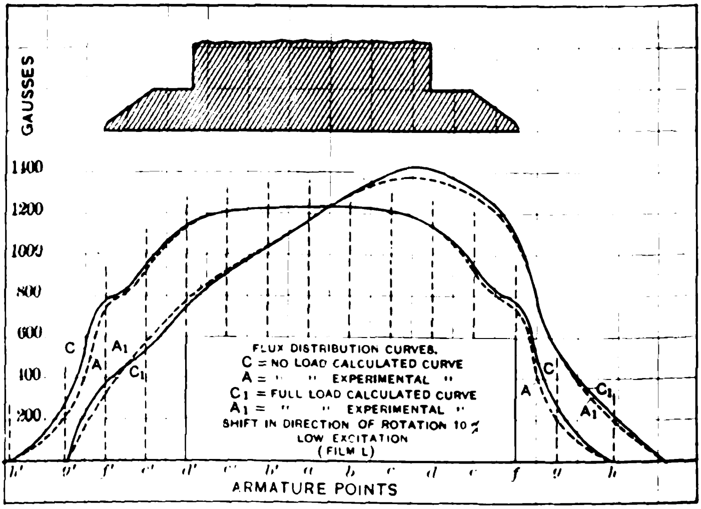

Fig. 17

The second point had to do with the methods ordinarily given for calculating the demagnetizing ampere-turns of an armature. As ordinarily taken these ampere-turns occupy the space designated by the double angle between the brush position and the no-load neutral. These experiments, however, show that as the load comes on the armature the real neutral shifts in the direction of rotation, the effect being exactly the same as if the poles themselves were rotated, relative to the brushes, a like amount. Furthermore, the position of the flux curve is affected very little by brush position, so that it is erroneous to measure to the no-load neutral in the calculation of the demagnetizing ampere-turns. Obviously the true point for load conditions can only be found by developing the flux distribution curve and, when this is done, by the methods herein given the element of cross magnetization and demagnetization vanishes from the calculations, the extra ampere-turns needed for overcoming the armature effects being found directly after the area of curve *B* is obtained and compared with curve *A*.

The experiments show that the effect of the so-called cross magnetizing ampere-turns is much larger for a given case than has usually been charged against them and that the effect of the demagnetizing ampere-turns is much smaller than the values given by the usual methods of calculation.

In closing, the writer wishes to express his sincere appreciation for the untiring efforts of Messrs. R. E. Pumphrey, C. S. Beardsley, H. Kessel and J. B. Sheadel, members of the class of 1911, School of Electrical Engineering, Purdue University. These men assisted the writer in the performance of the tests above described and used the experiments as a basis for their undergraduate theses.

A paper to be presented at the Pittsburg Meeting of the American Institute of Electrical Engineers, April 25-27, 1912.

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(*Subject to final revision for the Transactions.*)

ELECTRICAL CONTROL OF A LARGE MINE HOIST

BY H. W. CHENEY

The most serious problem encountered in the application of electric drive to large mine hoists is that of electrical control. It is necessary, in order to secure continued successful operation of an electric hoist, to furnish a control system which is absolutely reliable at all times. The design must be such that all parts of the apparatus will withstand the most severe, and even unreasonable, conditions of service without giving trouble and without repeated attention and repairs. It should be so designed that it is impossible for the operator to damage the controller or any part of the machinery by a wrong movement of the operating handle or by misjudgment of conditions.

This may be said of electrical control in general, but it applies with particular force to mine hoists, which are usually located remote from supply centers, are operated by men who are unfamiliar, as a general rule, with electricity, and where delays in operation mean tremendous losses to the mining companies.

In the electrical control of large induction motor-driven hoists, of which there are, to date, very few in this country, conditions are unusually exacting. The embodiment of all the desirable features of control for this class of service is a problem of no small moment, and is deserving of the best efforts and attention of engineering talent, for the advantages of the use of large induction motor-driven mine hoists are many and their use will become more general with the advent of suitable means of control.

It is the purpose of this paper to give a description of the general layout of a mine, an electrically driven mine hoist, a more complete description of a novel control system embodying a liquid rheostat employed for the the control of the hoist motor, and to outline some of the tests made upon the entire outfit during actual operation.

An electrical hoist (Figs. 1 and 2, Plate V) was installed at the No. 3 iron mine of the Woodward Iron Company at Woodward, near Birmingham, Ala., and was ready for operation in December 1909. It is of the unbalanced type, and consists of a single drum 8 ft. (2.4 m.) in diameter and 40 in. (1.01 m.)long, with winding space for 2,500 ft. (762 m.) of 1½-in. (3.8 cm.) wire rope. The drum is provided with a band brake which is automatically applied by a weight and released by air pressure under the control of the operator. It is driven by a 500 h.p., three-phase, 25-cycle, 375-rev. per min. wound rotor induction motor through a flexible coupling, triple reduction gear and an air-operated friction clutch of the Lane type. The hoist is designed for a maximum rope speed of 750 ft. (228.6 in.) per minute, and a maximum rope pull of 25,000 lb. (11,339 kg.)

Provision is also made for hand operation of the clutch and band brake from the operator's platform to provide means for operation in case of emergency or failure of the air supply.

An important feature of the hoist consists of means for automatically applying the brake in case the supply of currrent to the hoist motor fails. This consists of an alternating current solenoid, energized from the supply circuit through a potential transformer, so arranged that when the solenoid circuit fails the core of the magnet drops and actuates an air valve on the brake cylinder, allowing the brake to be set as usual by gravity.

The plan and profile of the mine where this hoist is installed, as developed at the time of installation, is illustrated in Fig. 3. It will be noted that a uniform grade of approximately 7¼ deg. and 676 ft. (206 m.) in length reaches from the surface to the knuckle, and that the slope beyond the knuckle varies, but is approximately 25 to 30 deg., although local faults may increase this grade materially at points. Branch headings are designated as "first left," "first right," "second left," "second right," etc. These headings may eventually be developed to a length of from one-quarter to one-half of a mile, (402 m. to 804 m.) or until met by similar headings from an adjacent mine.

The track of the mine is 42-in. (1.07 m.) gage, and standard mine cars weighing 2,500 lb. (1,134 kg.) empty are used. As many as five cars are hitched in train and each may be loaded

PLATE V
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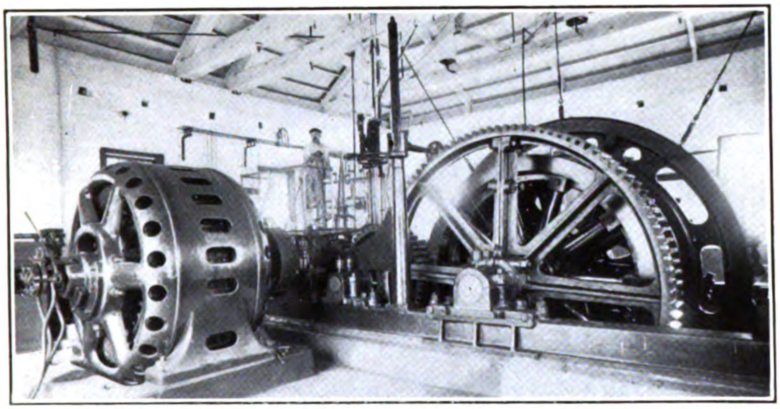

FIG. 1 [CHENEY]

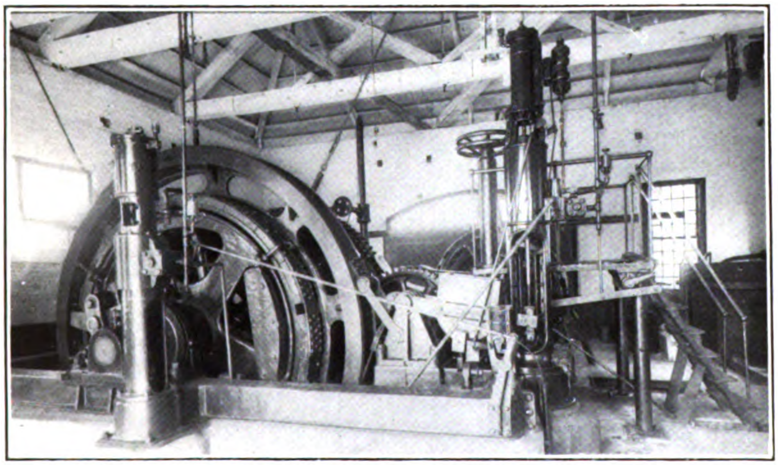

FIG. 2 [CHENEY]

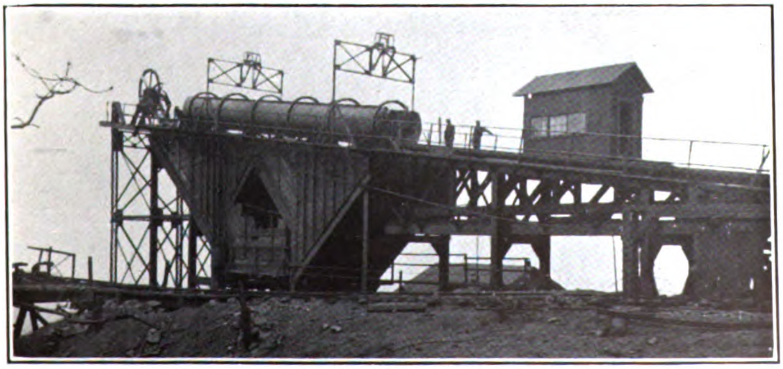

FIG 4 [CHENEY]

with approximately four tons* of ore making a total load, including cars, of 52,500 lb. (23,813 kg.)

The track curves at the branch headings are very sharp; in most cases the radius does not exceed 8 ft. (2.4 m.) By reference to the plan and profile of the mine, it will readily be seen why the highest peak of the hoist load occurs as the loaded cars are being pulled around this sharp curve onto the incline. Often loaded cars become derailed at this point, owing to the sharp curve, and must be pulled onto the track at the curve. It is this contingency that calls for the greatest effort on the part of the hoist and draws the greatest amount of power from the transmission line.

The tipple shown in Fig. 4 is of more than passing interest, and consists of a rotatably mounted cylindrical framework into which the train of mine cars is drawn. The wheels of the cars run under a supplementary rail in the framework which maintains the relation of the cars and track while dumping. The ore cars are automatically dumped by the rotation of the cylinder which is accomplished by means of compressed air under the control of the operator. A large sheave is placed at the outer extremity of the tipple over which the wire rope is carried from the drum of the hoist and attached to the mine cars. This rope also passes over wide sheaves or rollers at intervals along the track during the descent of the cars into the mine, thus relieving the friction and wear of the rope. During the hoisting operation, as the cars approach the tipple they are stopped for a moment at the weighing platform shown in the cut, where each trainload of ore is

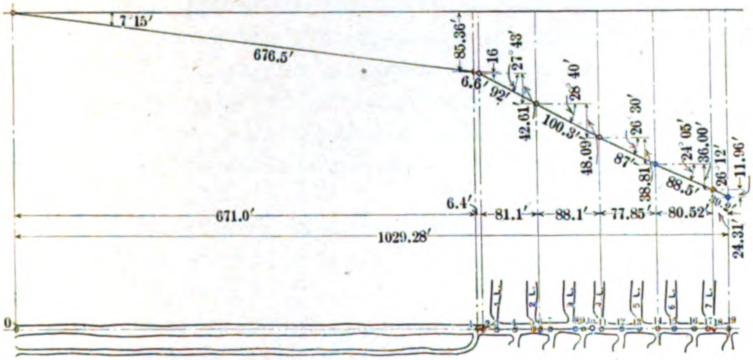

FIG. 3

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*One long ton = 1.016 metric tons.

weighed and recorded. After being dumped into the huge hopper underneath the tipple, the ore, which is in the form of rock passes through the crusher into the cars which are used to haul it to the blast furnaces.

Only two men are required at the surface during regular operation; the hoist operator and the weigher.

The hoist at this mine is approximately four miles from the power house of the company, and electrical energy is transmitted at a voltage of 3300 and a frequency of 25 cycles over a three-phase system.

The hoisting engine and the electrical control equipment are housed in a brick building which is located on the slope of the hill just above the mine entrance.

The 3300-volt lines are brought into the hoist house and connected to high-tension bus bars. Two switchboard panels are installed consisting of the main motor panel, upon which are mounted an overload no-voltage release oil switch and an ammeter with a current transformer, and a line panel, upon which a non-automatic oil switch, an ammeter with a current transformer, and three three-pole single-throw fused knife switches are mounted.

Three transformers of 50 kw. capacity, having a ratio of 3300 to 220 and 110 volts, are connected in delta to furnish energy for lighting, for running an electrically-driven air compressor used as an auxiliary, and a circulating pump for the liquid rheostat. An electrolytic lightning arrester is also installed for protection against lightning disturbances, which are frequent in the locality of this installation.

Fig. 5 shows a diagram of electrical connections of the control system. Referring to this diagram, the electrical operation of the hoist is as follows:

The non-automatic oil switch on the transformer panel is first closed, thus exciting the transformers. The three pole single throw knife switches on the same panel are then closed, supplying alternating current at 220 volts to the motor of the water circulating pump, to the air compressor motor through a pressure regulator switch, to the no-voltage coil of the main oil switch on the motor panel, and to the terminals of a switch connected to the brake solenoid. This latter switch is mechanically connected to the overload no-voltage release oil switch so that both are opened and closed simultaneously. The overload no-voltage release oil switch is now closed and the hoist is ready for regular operation from the hoist platform. It should be stated that in the oil switch used, the overload coils are direct series trip coils, and the overload and no voltage coils act independently of each other on the mechanism to trip the switch. A forward movement of the operator's control lever closes the primary switch making final connection to the primary winding of the induction motor for hoisting, while a reverse movement of the same lever closes the primary oil switch making reversed connection with the primary winding of the motor for lowering. It is necessary to provide the reversing feature since the slope of the mine near the entrance is not sufficient for empty cars to unwind the drum of the hoist by gravity.

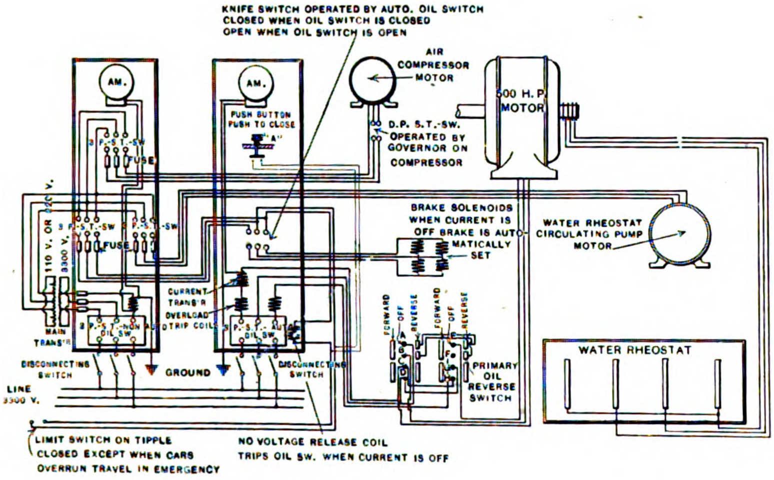

KNIFE SWITCH OPERATED BY AUTO. OIL SWITCH
CLOSED WHEN OIL SWITCH IS CLOSED
OPEN WHEN OIL SWITCH IS OPEN
AM.
AM.
PUSH BUTTON
PUSH TO CLOSE
"A"
3 P.-S.T.-SW
FUSE
AIR COMPRESSOR MOTOR
D.P. S.T.-SW.
OPERATED BY GOVERNOR ON COMPRESSOR
500 H.P. MOTOR
110 V. OR 220 V.
3300 V.
3 P.-S.T.-SW
FUSE
3 P.-S.T.-SW
MAIN TRANS'R
CURRENT TRANS'R
OVERLOAD TRIP COILS
3 P.-S.T.-NON AUTO OIL SW.
3 P.-S.T.- AUTO OIL SW.
BRAKE SOLENOIDS WHEN CURRENT IS OFF BRAKE IS AUTOMATICALLY SET
WATER RHEOSTAT CIRCULATING PUMP MOTOR
FORWARD
OFF
REVERSE
FORWARD
OFF
REVERSE
PRIMARY OIL REVERSE SWITCH
WATER RHEOSTAT
DISCONNECTING SWITCH
GROUND
DISCONNECTING SWITCH
LINE 3300 V.
LIMIT SWITCH ON TIPPLE CLOSED EXCEPT WHEN CARS OVERRUN TRAVEL IN EMERGENCY
NO VOLTAGE RELEASE COIL TRIPS OIL SW. WHEN CURRENT IS OFF

FIG. 5

The secondary windings of the motor are connected to the terminals of a liquid rheostat for varying the resistance of the secondary circuit and controlling the speed of the motor. The operation of this rheostat is controlled by the same lever that is used to open and close the primary switch. The details of construction of the lever mechanism will be explained later.

Particular attention is called to the limit switch. This switch is placed on the tipple in such a position that if the cars overrun it will be mechanically opened by a track lever. The circuit of the no-voltage release coil of the main oil switch passes through this limit switch, and in case the car passes the limit of travel the oil switch and solenoid brake switch are automatically opened, thus cutting off the motor current and automatically setting the brake regardless of the position of the operator's handle. In case of overload or short circuit sufficient to trip the oil switch, the brake is also set by the means above described.

A push button which is normally open is provided on the motor panel for closing the circuit of the no-voltage release coil of the oil switch after the cars have overrun in order to back them into position again for regular operation. This is purposely arranged so that an extra man will have to be called upon to help the operator after an automatic stop at the tipple has been made. This provision was made so that carelessness at this point would be reduced to a minimum on account of the inconvenience caused by it.

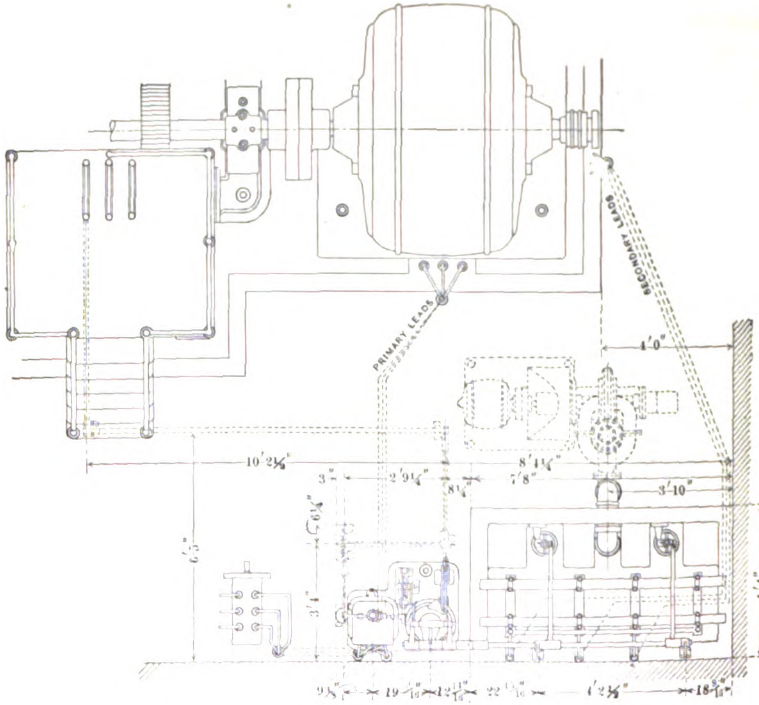
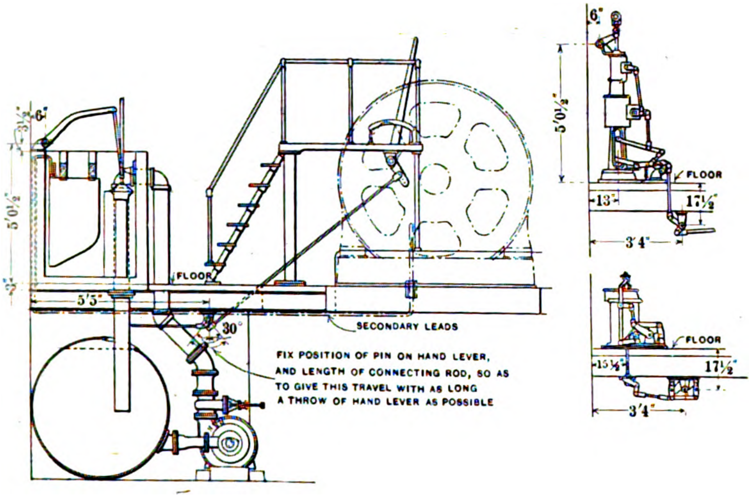


FIG. 6

Another safety feature worthy of notice is a provision for the automatic opening of the overload no-voltage oil switch in case the non-automatic transformer switch is opened, thus cutting off supply current to the auxiliary apparatus, and also making it impossible to hold the overload no-voltage switch closed unless the non-automatic transformer switch has first been closed.

The general layout of the controller in its relative position to the cage of the hoist is shown in plan in Fig. 6, and in elevation in Fig. 7. The controller consists of a primary switch for closing, opening and reversing the 3300-volt primary connections to the motor, and a liquid resistance in the secondary circuit of the motor to limit the line current for the required torque at starting and for speed regulation during regular operation.

The primary switch is oil immersed and is of the rotary multiple break type. It is so arranged that when turned in a clockwise direction from the off position connections are made for forward rotation of the motor, while if turned in the opposite direction the motor is reversed.



FIX POSITION OF PIN ON HAND LEVER, AND LENGTH OF CONNECTING ROD, SO AS TO GIVE THIS TRAVEL WITH AS LONG A THROW OF HAND LEVER AS POSSIBLE

FIG. 7

The liquid rheostat for the secondary circuit is shown in detail in Fig. 8, and consists of a concrete tank in which stationary plates of cast iron are suspended as electrodes. Electrolyte is then raised or lowered in the tank by mechanical means to vary the resistance between the electrodes. The electrodes are hung on insulating supports which are set in a recess in the concrete tank near the top. They are ribbed to give maximum contact area with a minimum amount of space and are made of special form which was carefully worked out to give a smooth speed and accelerating curve. Four electrodes are used for the three-phase circuit, the two outer ones being connected together and to one phase. By proper spacing, which was determined by preliminary test, the correct amount of resistance and a balanced three-phase star-connected resistance is obtained at all times. By the use of ribbed angle plates, which are bolted to the electrodes near the top, and which overlap each other with a small intervening space, the effective distance through the liquid between plates is gradually decreased, and the effective area of the plates is gradually increased as the liquid is raised in the tank. At the highest level of the liquid the plates are practically short circuited by the electrolyte which flows in and fills the small space between the horizontal portions of the angle plates.

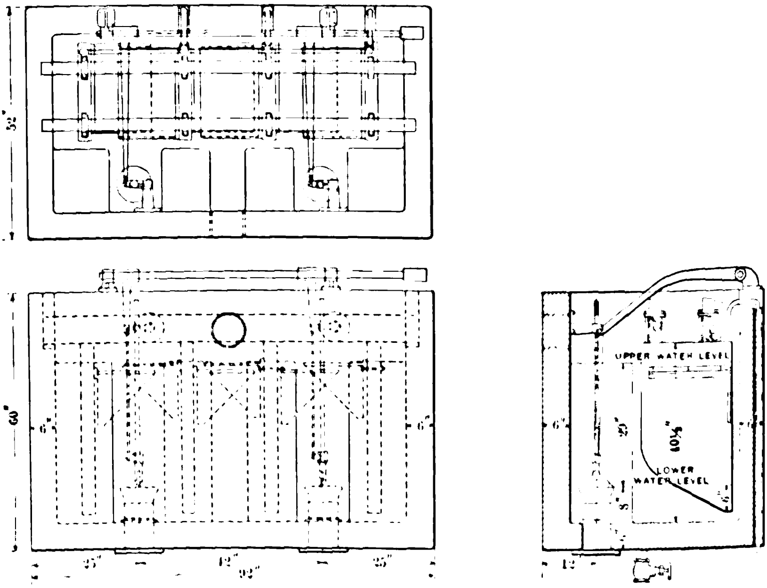


FIG. 8

The electrolyte used consists of ordinary well water in which a small quantity of salt was dissolved. The amount of salt which gave the bests results with the water used in the liquid rheostat where this hoist was installed, was found to be nine pounds of salt per one thousand gallons of water, or approximately one-tenth of one per-cent by weight.

A cooling tank is located in the basement directly under the rheostat tank, and a centrifugal pump serves to pump the liquid from the cooling tank into the rheostat tank and to keep it in continuous circulation. This pump is driven by a 220-volt squirrel-cage induction motor and is run continuously. A gate valve is placed in the discharge pipe of the pump to regulate the rate of flow into the rheostat tank.

The height of liquid, and consequently the amount of resistance in the secondary circuit of the motor is regulated by means of two movable weirs in the form of pipes which are raised or lowered through an opening near the bottom of the tank. By the use of the pipe construction for the weirs, all friction, due to side pressure of the liquid, is eliminated. The arrangement is such that all of the liquid cannot escape through the weirs when in their lowest position. The lower ends of the electrodes are thus always immersed and the secondary circuit is never opened. The areas of the opening through the weirs is approximately double that of the inflow pipe, and is sufficient to allow the maximum amount of liquid in the rheostat tank to escape into the cooling tank in ten seconds, including the continuous discharge from the pump. With the gate valve wide open and the weirs raised to the highest point, the rheostat tank will fill in approximately 20 seconds. This time may be increased as much as desired by adjusting the opening of the gate valve.

All of the metal parts inside of the tank, with the exception of the cast iron electrodes, are heavily galvanized to prevent deterioration from rust.

Since compressed air is utilized for actuating the clutch and brake mechanism of the hoist, the control mechanism was designed for air operation throughout. A double acting air engine is connected to the weirs through a rock shaft and levers and to the primary oil switch through a reversing clutch in such a manner that the first part of the upward piston stroke closes the oil switch, and a continuance of this movement raises the weir. This engine is provided with an adjustable oil cataract and a floating lever valve device, by means of which the air piston may be stopped and held at any point corresponding to the position of the operator's lever.

The operator's lever, which is located on the cage or platform of the hoist, rests at the central point of a notched sector when the controller is at "off" position. When the lever is moved away from the operator, the first movement sets the clutch on the primary oil switch for clockwise movement of the rotating member of the switch, and a further movement of the lever opens a valve and admits air to the air cylinder, which first closes the switch and then raises the weirs to any desired height. To stop the motor the lever is returned to the "off" position. A mechanical interlock is provided at this point to prevent the operator from throwing the lever to reverse position until the weirs reach the lowest point and the maximum secondary resistance is inserted. In case it is desired to run the hoist motor in a reverse direction, the operator's lever is moved toward the operator when the clutch on the primary switch is first set for counter-clockwise movement of the rotating member of the switch, and the balance of the operation is the same as before described, except that the motor runs in the reverse direction.

The by-pass of the oil cataract on the air piston is adjusted for maximum allowable piston speed at which no jar or shock to the mechanism occurs when the operator's lever is thrown quickly from one extreme to the other. The gate valve is set for minimum time of acceleration for a given primary current with an average load of ore on the average grade. Semi-automatic acceleration is thus obtained; that is, if the operator throws his lever to the extreme position, the acceleration of the hoist is automatic and will be accomplished in as quick a time as can be done without too heavy a draft of current from the line, while if it is desired to regulate the rate of acceleration the operator may allow the operating handle to remain at any intermediate point between the off and the full speed position, which allows regulation anywhere inside of the limits for which the controller is set.

During the tests which followed the installation of this controller, every conceivable movement that could be given the operator's lever was tried, and it was found that no damage whatever could be done to any part of the outfit by improper manipulation of the control lever.

Owing to the lack of reliable data from the experience of others, it was found necessary, before designing this controller, to make preliminary tests to determine the necessary data to be used. A large number of tests were made to determine the proper surface area of electrodes per ampere of current. It was found that with alternating current two amperes per square inch could be used as a fair average, and that the area could be varied between one ampere per square inch for continuous service and three amperes per square inch for intermittent service without undue deterioration of electrodes or excessive generation of gases.

Tests were made to determine the inches per volt drop at different temperatures for different solutions. Fig. 9 shows a typical curve obtained for a 5.4 per cent solution of common salt ($NaCl$) in distilled water, by weight, and also for a solution of caustic soda ($NaHO_4$). Curves were also consulted for solutions of sulphuric acid (H_2SO_4), caustic potash (KHO), sodium sulphate (Na_2SO_4), and copper sulphate ($CuSO_4$), but the conclusions reached were that good average results could be obtained by the use of common salt solution and that its use would be preferable for a mine hoist controller on account more particularly of the ease with which it can be obtained and on account of its mild action on the metal electrodes and piping.

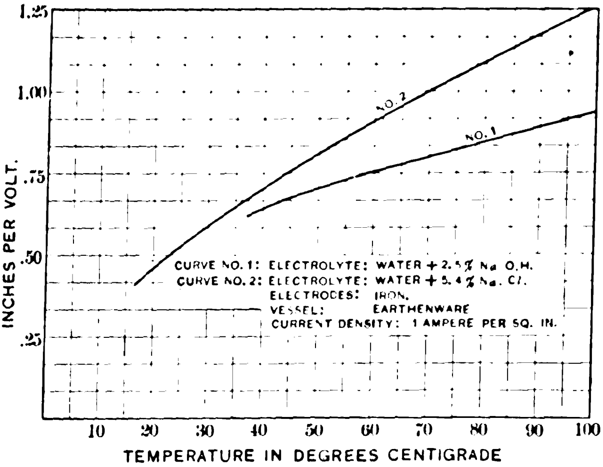


FIG. 9

A series of tests were made to determine the most feasible arrangement of plates to obtain balanced three-phase resistance and at the same time to conserve the volume of the rheostat tank. Several schemes were proposed and tried, and while a number of different arrangements were found which gave perfect balance, the one shown in Fig. 10 was adopted as being best suited to a tank of rectangular construction and saving of space.

While theoretically, the watts dissipated at a given temperature depend upon the surface area of the liquid and not upon its volume, experiment demonstrates that calculations based on watts dissipated per cubic inch (16.4 cu. cm.) of liquid are more reliable and may be followed with the best results in actual practice. Fig. 11 shows a curve giving the approximate rise in temperature which may be expected for from one to four watts dissipated per cubic inch (16.4 cu. cm.) of solution.

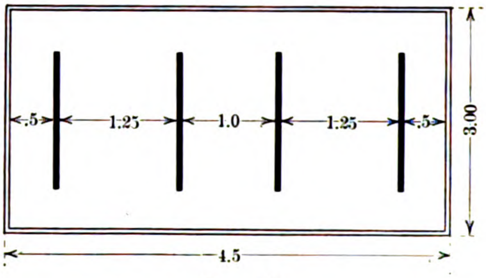


FIG. 10

For the purpose of making tests on the hoist and controller a portable instrument rack was constructed, upon which was mounted a graphic recording polyphase wattmeter, a graphic recording ammeter, a graphic recording speed indicator, two indicating voltmeters, two indicating ammeters, and a polyphase integrating wattmeter.

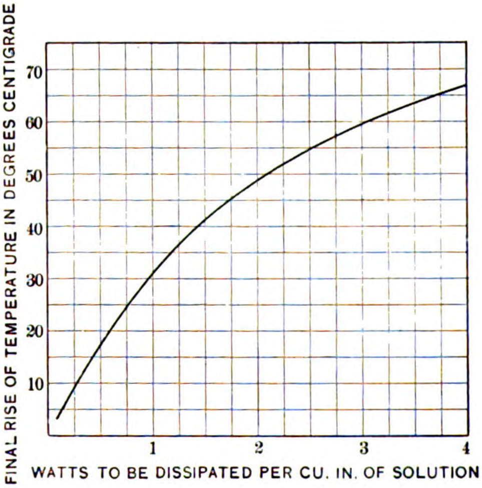


FIG. 11

Owing to the time of the hoisting cycle, it was necessary to speed up the record strips in the recording instruments to about

6 in. (15 cm.) per minute. This was done by driving the instruments through a countershaft by means of a small synchronous motor mounted upon the rack. The recording speed indicator consisted of a voltmeter connected in circuit with a magneto driven by the hoist motor. The recording wattmeter, ammeter, and the integrating wattmeter, were connected in the primary circuit of the hoist motor and the indicating voltmeters and ammeters were connected in the secondary circuit. Two recording or integrating wattmeters, which are unaffected by frequency changes, and, which are reasonably accurate over a wide load range, were connected in the secondary circuit of the hoist motor,

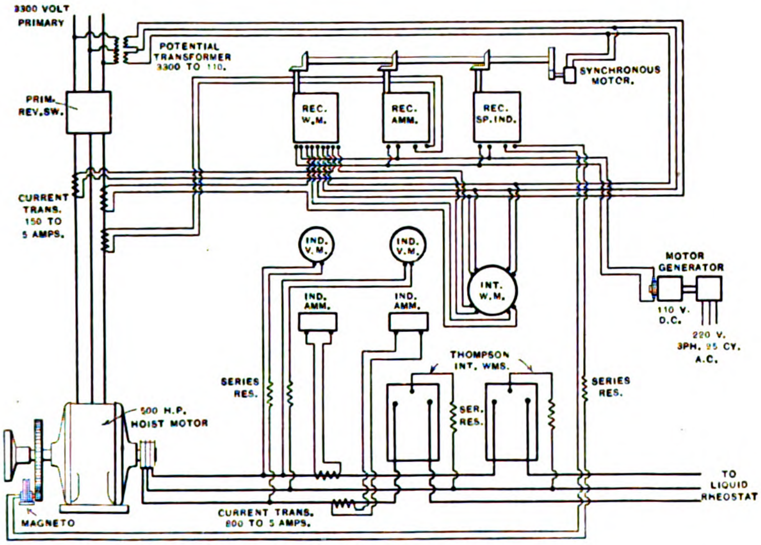


FIG. 12

Observations as to line voltage, frequency, etc. were made upon the regular switchboard instruments.

A diagram showing instrument connections used in making tests is shown in Fig. 12. All instruments were carefully calibrated in factory laboratory preparatory to the test.

Readings were made and records taken on a large number of complete trips during regular operation of the hoist soon after its installation. No special preparation was made in the mine in regard to loads and heights of lift, but accurate records were kept of the weights of each load and of the heading of the mine from which it came. The hoist was operated during the test by regular employees of the mining company, who were at that time unaccustomed to the use of electric hoists. The track had been relaid to a wider gauge and new cars of greater capacity had been installed when the operation was changed over from steam to electricity. The track and cars were consequently in good condition.

Fig. 13 shows typical graphic meter records giving kilowatt input, primary amperes and speeds during one complete cycle of 8¾ minutes and from the No. 4 left heading with a five-car load weighing 37,700 lb. (17,100 kg.) gross, or 25,200 lb. (11,430 kg.) of ore net.

Based upon data obtained from this curve and from the observations taken during the trip, which represents a fair average of the regular performance of the hoist at the time the tests were made, calculations show the combined efficiency of the hoist and controller during the hoisting period to be 36.7 per cent.

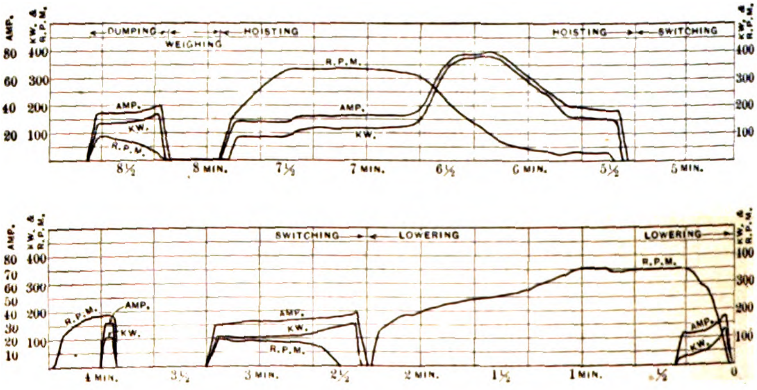


FIG. 13

From the records of these tests exact information is available as to the watt-hours input per ton-foot of ore hoisted, energy output and actual work done, percentage of loss of the liquid rheostat controller and total combined efficiency of the entire outfit.

The nature of the work to be done in electrical hoisting is so varied and conditions encountered are so different in different mines, that a hoisting equipment which is entirely suitable for one class of work may be out of the question on another class of work.

In a great many cases the efficiencies, so far as actual consumption and energy input are concerned, are a secondary consideration to the speed of operation, continuity of service, reduced manual labor, reduced maintenance cost, and reduced initial cost of the hoisting equipment.

In each case conditions must be very carefully studied to determine the type of hoist most suitable for the work in order that the total operating expenses for a given result may be as low as possible, and in order that the initial expense of the equipment may not be prohibitive.

It is a well known fact that rheostatic control of electric motors, whether used for alternating or direct current, is inherently inefficient. There are, however, innumerable places where the fact remains that it is good engineering to employ this form of control owing to simplicity in design and operation.

Where it is desired to employ alternating-current induction motors for hoisting operation, rheostatic control is necessary in order to properly regulate the speed of operation. The use of such motors for hoisting service is increasing, due to low maintenance cost, low initial cost of plant, and reliability of service obtained.

The extremely smooth acceleration obtained with the liquid rheostat, but which is not possible with other types of control, is of inestimable value in mine hoisting. It is possible to move the rope a foot or two very slowly and without jerks or sudden impulses. This is of great advantage in taking up the slack in the rope and in pulling the loads out of the branch headings. Practical operation has demonstrated that there are very few wrecks inside of the mine employing this form of control as compared with the numerous wrecks had in adjacent mines where steam hoists are used.

In conclusion, it is the belief of the writer that the liquid rheostat type of control offers possibilities which have not received warranted attention in this country, and that with proper development along this line a highly satisfactory solution is available for the problems encountered in the control of electric mine hoists, especially those employing alternating-current induction motor drive.

A paper to be presented at the Pittsburg Meeting of the American Institute of Electrical Engineers, April 25-28, 1912.

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(Subject to final revision for the Transactions.)

NOTES ON THE USE OF ALTERNATING CURRENT IN UNLOADING COAL

BY W. N. RYERSON AND J. B. CRANE

The receipts of coal in Duluth-Superior Harbor increased from 2,600,000 tons* in 1900 to 8,300,000 tons in 1910. This coal comes principally from Pennsylvania and West Virginia and is brought by rail to Lake Erie ports where it is loaded into boats for transportation to Duluth and Superior. Of the receipts in 1910, two million tons was anthracite and the remainder bituminous coal. At Duluth-Superior Harbor the coal is unloaded from the boats and stored for future demand or loaded directly into cars for shipment to various points in Minnesota, North Dakota, South Dakota and Montana.

The storage capacity of all the docks at this port increased from 1,000,000 tons in 1900 to over 5,000,000 tons in 1910.

In 1906 there were two docks equipped for the use of electrical energy, both using direct current, one of them purchasing current from the local lighting company and the other owning and operating its own generating plant. In 1911, eleven of the twenty-one coal docks were equipped for the use of electrical energy and nine of these are using alternating current directly on the hoisting apparatus while another has installed a synchronous converter in order to supplement its existing direct-current generating equipment by the use of purchased power.

In 1909, twenty-six per cent of the coal received was handled by electrical energy, in 1910, forty per cent, and in 1911, it was estimated that sixty per cent of the total coal received would be handled by the use of electricity.

Before the introduction of electrical energy, the largest dock had a storage capacity of 250,000 tons, while two of the newer docks have storage capacities of 1,000,000 tons each and another is projected of this same capacity but with provision for an ultimate storage of 2,000,000 tons.

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*One long ton = 1.016 metric tons.

The coal handling machinery as at present installed is divided into three types: bridge tramway, cable car, and man trolley.

Bridge Tramway. Figs. 1 and 2 give a general idea of the equipment on one of these docks.

The installation consists of moving bridges, locomotive cranes, box car loaders, and screening towers.

The boats are moored to the unloading side of the dock. In case the unscreened coal is to be shipped out immediately the bucket takes the coal from the boat and loads it into the cars at the opposite end of the dock. In case the coal is to be screened the bucket carries it to the rear end of the dock and dumps it into the screening towers. Moving buckets carry the screenings on to the screenings pile at the rear of the dock. The screened coal is loaded into cars by gravity. Coal for storage is dropped directly onto the storage pile.

Twenty-five-cycle, three-phase, 13,000-volt power is delivered to the terminals of a transformer house. Three 500-kw, three-phase transformers reduce the pressure to 440 volts for distribution about the dock. This distribution is accomplished in a novel manner. Posts about four ft. (1.2 m.) high, as shown in Fig. 2 are spaced at intervals along both ends of the dock. Three contacts about 15 in. (38 cm.) apart are placed vertically on these pots and the current is transferred to the moving machinery by means of shoes, which span two posts at a time. The cables for supplying current to the contacts are carried in troughs about one ft. (30 cm.) above the ground and protected by means of metal covers, which can be easily slipped off for the purpose of making repairs to the cables.

The bridges have an extreme length of 506 ft. (154.2 m.). The buckets are controlled from cabs at either end of the bridge. They operate by means of cables running over sheaves from the cabin on top of the bridge. One 225-h.p., three-phase, 440-volt wound rotor motor drives the hoist for closing and hoisting the bucket. For moving the bridge two 75-h.p. motors are used.

The buckets are all of the clam shell type and on three of the four bridges on this dock weigh seven tons and hold three tons of coal. The fourth bridge, installed in the spring of 1911, has a bucket weighing six tons and hoists four tons of coal. On this

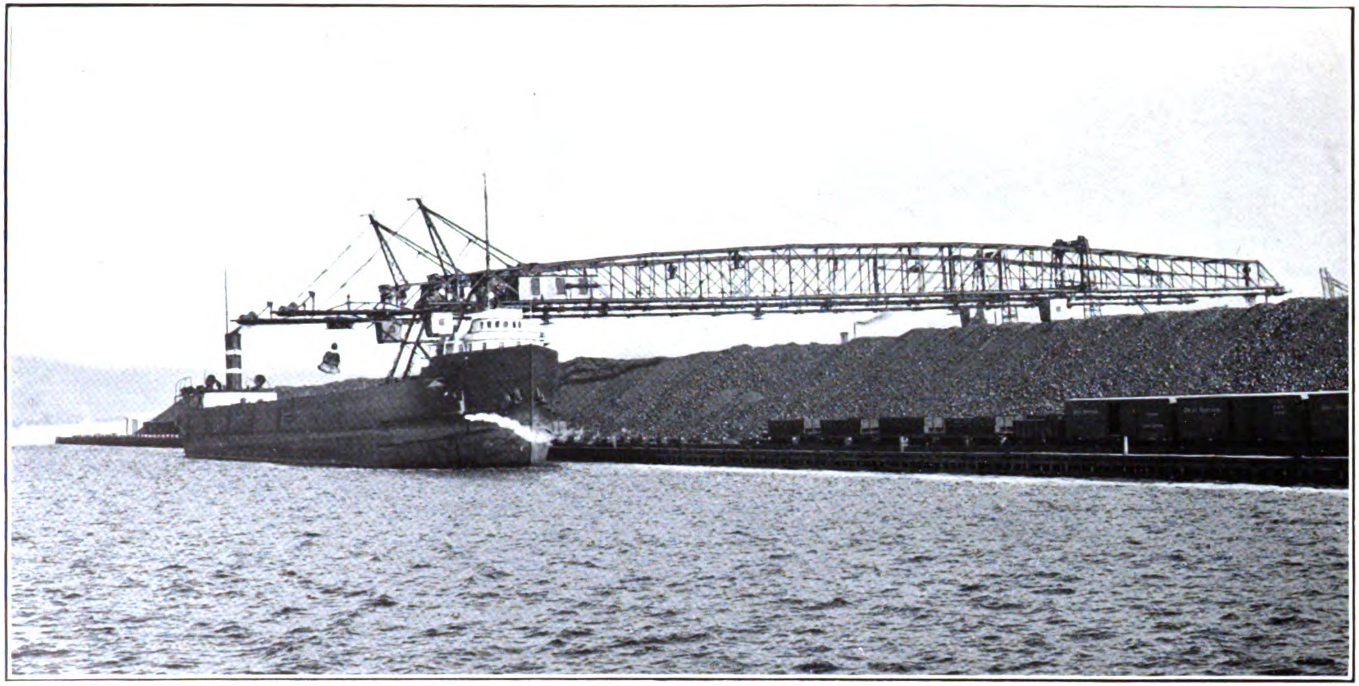

FIG. 1.—BRIDGE TRAMWAY
Showing bridge unloading from boats

[RYERSON AND CRANE]

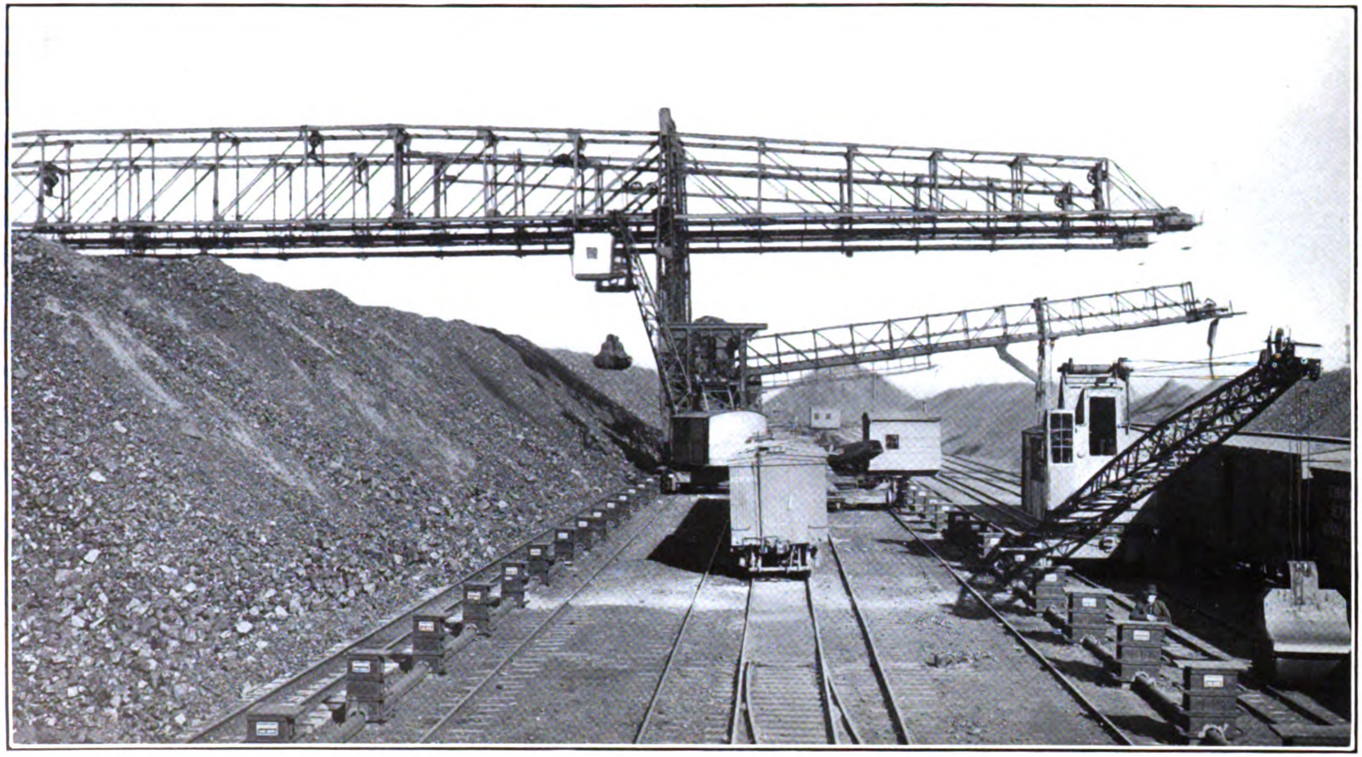

FIG. 2.—BRIDGE TRAMWAY [RYERSON AND CRANE]

Showing locomotive cranes, box-car loaders, screening towers and current posts.

latter bridge a 375-h.p. motor is used for hoisting and closing the bucket and one 225-h.p. motor for moving the bridge.

The older type of bridge has a hoisting speed of 300 ft. (91 m.) per minute and was guaranteed to make 60 trips and unload 180 tons of coal per hour, and has made 100 trips and unloaded 300 tons of coal in one hour.

The new bridge has a hoisting speed of 600 ft. (182 m.) per minute and has shown a capacity of 500 tons of coal per hour. This bridge has proved so successful that it is proposed to install similar apparatus on one of the other bridges this winter.

The control system on the bridges is alternating-current magnetic control and has given no trouble in three years of operation.

The braking is done by means of friction brakes released by solenoids. Hardwood shoes were at first used for this purpose. These caused considerable trouble from heating, and for the past two years asbestos shoes have been used with good satisfaction.

The locomotive cranes shown in Fig. 2 are equipped with 75-h.p. wound rotor motors and are used for moving cars, hoisting coal from the screenings pile into cars, and loading coal from the side of the main pile into the loading hopper.

The box car loaders shown in Fig. 2 are equipped with 12-h.p. wound rotor motors. These machines are used for moving cars and loading coal into box cars. Most of the cars loaded are of this type, the cars bringing wheat to Duluth and taking coal from Duluth. The loaders have an arm extending into the door of the car on the side opposite the receiving spout. The coal strikes the end of the arm and is thrown first to one end and then to the other by means of a reversible scoop operated from the cab of the loader by the operator.

All the electrically operated docks use the same type of box car loader.

The screening towers consist of hoppers into which the coal is dumped, and from which it falls into the car over screens. The screenings are emptied on to the screenings pile by means of moving buckets, operated by a 27-h.p. motor.

With three bridges in operation this dock has unloaded boats containing 10,500 tons of coal in 18 hours and with four bridges in operation has unloaded a similar quantity in 13 hours.

No trouble of a serious nature has developed in three years' operation and the manufacturers of this equipment and the owners of the dock are satisfied with the results obtained. The dock was extended from 1200 to 2600 ft. (365 to 792 m.) in length this spring and some trouble was experienced due to excessive drop in voltage at the further end. This has been taken care of by moving one of the 500-kw. transformers to the lower end of the dock and running an underground 13,000-volt circuit to this point.

Cable Car. This installation, shown in Figs. 3 and 3A, consists of an elevated railway on which are mounted the hoisting towers and tracks for cars. The following apparatus is on the dock proper: screening pockets, unloading pockets, traveling bridge, conveyor belts, car loaders, and box car loaders.

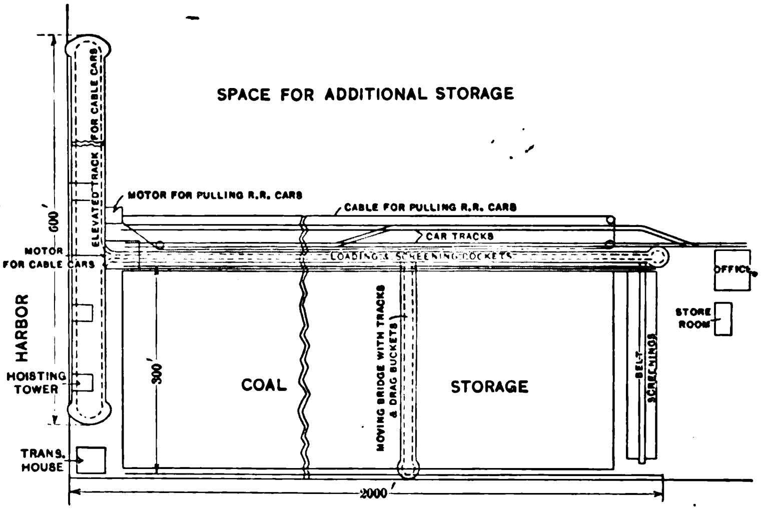
SPACE FOR ADDITIONAL STORAGE
ELEVATED TRACK FOR CABLE CARS
MOTOR FOR PULLING R.R. CARS
CABLE FOR PULLING R.R. CARS
CAR TRACKS
LOADING & SCREENING POCKETS
600'
MOTOR FOR CABLE CARS
OFFICE
HARBOR
STORE ROOM
HOISTING TOWER
300'
COAL
MOVING BRIDGE WITH TRACKS & DRAG BUCKETS
STORAGE
BELT
SCREENINGS
TRANS. HOUSE
2000'

FIG. 3A.—ARRANGEMENT OF DOCK FOR CABLE CAR EQUIPMENT.

Energy is delivered to this dock at 13,000 volts, three-phase, 25 cycles, and is reduced to 440 volts by means of three 500-kw., three-phase transformers. The energy is delivered to the hoisting towers and traveling bridge by means of trolley wires.

The boats at these docks are moored at the end of the dock. As shown in Fig. 3, there are three hoisting towers with swinging booms. These booms are swung over the boat, and buckets take the coal from the boat and empty it into a hopper. From the hopper it is loaded automatically into cars and these cars, operated by cables, empty the coal into loading pockets; or if the coal is to be stored, the cars are shunted on the traveling

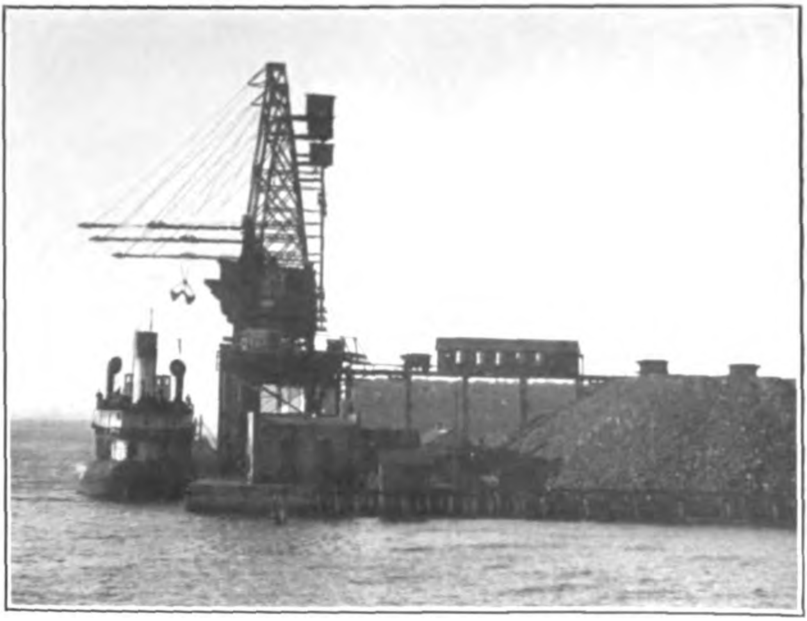

FIG. 3.—CABLE CAR [RYERSON AND CRANE]
Showing hoisting towers and elevated railway

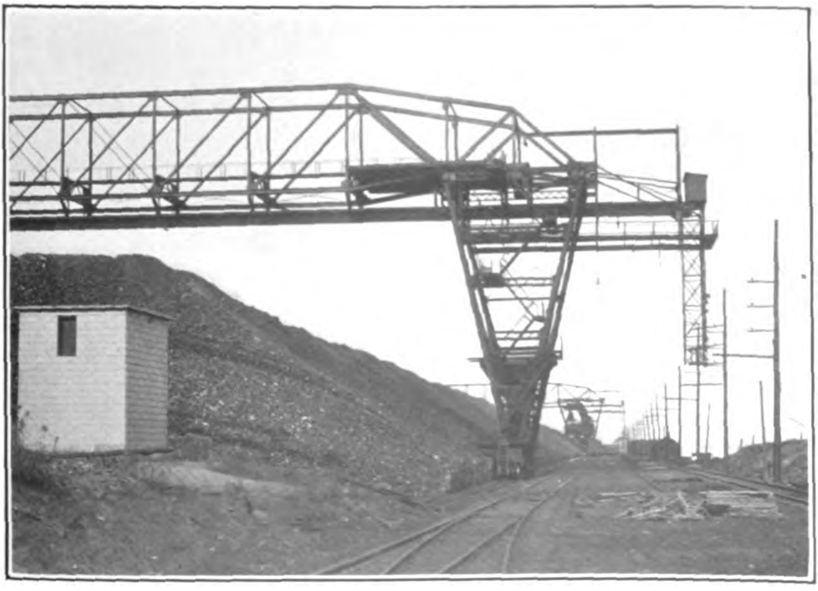

FIG. 4.—MAN TROLLEY [RYERSON AND CRANE]
Showing junction house, screening hopper, 13,000-volt catenary and 440-volt trolley

bridge and load directly onto the storage pile. In taking coal from the storage pile shovel buckets are used and these empty the coal into the loading pockets.

The hoisting towers are equipped with clam shell buckets weighing 6,800 lbs. (3,084 kg.) and holding two tons of coal. There is a counter-weight on these buckets weighing five tons. The motors are 200-h.p. wound rotor, 440-volt, three-phase, 25-cycle. The hoisting speed is 600 ft. (182 m.) per min. The control is pneumatic and small air compressors are mounted on each tower. The braking is by friction and asbestos shoes are used, the levers from the brakes being controlled directly by the operator. These buckets average 144 round trips per hour and three towers have unloaded an 11,246-ton boat in 18 hours. This type of tower has usually been installed with steam operated hoists and the manufacturers have claimed that the steam hoists were quicker. There are two other docks at this port using steam hoists of this type but neither of them has been able to do as rapid work as the electrically operated hoists.

The cable cars are 11 ft. (3.3 m.) long 5 ft. (1.5 m.) wide and 6 ft. (1.8 m.) high, and each holds four tons of coal. These cars pass under each hoisting tower and touch a lever which releases enough coal to fill the car one-third full. One 75-h.p. motor is used for operating the cables.

The screening and loading pockets are along the railroad tracks at one side of the dock and directly under the elevated cars. The loading pockets load directly into the cars by gravity. The screening pockets empty the coal into the cars after it has passed over the screens. The screenings fall on conveyer belts and are carried to the upper end of the dock and there emptied on to the screenings pile. One end of the moving bridge is connected to the elevated structure and the other rests on long legs, running on a track at the other side of the dock. The bridge is equipped with a loop track and in storing coal these tracks are connected to the elevated structure by switches and the bridge is moved along the dock as soon as one section is full. In loading coal from the dock two shovel buckets are used. These buckets hold two tons and empty the coal directly into the screening and loading pockets or into the cars, which in turn empty into the pockets. Wound rotor motors of 150 h.p. capacity are used to operate these buckets.

The conveyer belts for the screenings are 24 in. (61 cm.) wide and are operated by 25-h.p. motors. They operate at 450 ft. (137 m.) per minute and carry 100 tons of coal per hour.

For setting cars a cable is run along the railroad tracks, and is operated by a 32-h.p. motor. The box-car loaders are similar to the ones described under " Bridge Tramway."

This type of equipment has been very satisfactory and the only trouble experienced has been with the air control freezing in winter, due to moisture collecting in the pipes, and some trouble with the motors on the hoisting towers.

The vibration on the towers is so great that it is hard to brace the end connections of the stator windings so that they do not rub against each other and wear the insulation. It has been necessary to rewind the motors twice but it is thought that these are now braced securely enough to give no further trouble.

Man Trolley. The two types of equipment described above are adaptations of steam operated rigs to the use of electricity. The man trolley equipment is an effort to devise something particularly fitted to the use of electric motors. It is, in its simplest form, a traveling crane on legs but using a bucket instead of a hook.

There are in use here at the present time two types. One uses a hoisting speed of 300 ft. (91 m.) per minute and a trolleying or racking speed of 1,000 ft. (305 m.) per minute; the other uses a hoisting speed of 250 ft. (76 m.) per minute and a racking speed of 1,200 ft. (365 m.) per minute. Fig. 4 shows the first type of dock.

The equipment consists of traveling bridges, screening hoppers, car pullers, and box-car loaders.

The energy is delivered at 13,000 volts, three-phase, 25 cycles to the junction house, shown in Fig. 4, which contains oil switches, meters and lightning arresters. From this junction house the current is carried to 13,000-volt, three-phase catenary trolleys running the whole length of the dock. The transformers for reducing the pressure to 440 volts are located in the cabin at the top of each bridge. The 440-volt trolley for the box car loaders receives its energy from the transformers on the bridges. The machine shop and car pullers receive their 440-volt energy from a transformer located in the junction house. The boats are moored at the unloading side of the dock. The buckets empty the coal from the boat into the front hoppers if the coal is to go out unscreened and into the rear hoppers if it is to be screened. In case the coal is to be stored the buckets empty directly on the storage pile.

The buckets are of the clam shell type, weighing eight tons and carrying five tons of coal; the moving equipment, hoist, cab, air compressor, etc., weigh approximately fifty tons. Each hoist is equipped with two 150-h.p., three-phase, 440-volt, 25-cycle wound rotor motors. Both motors are geared together and used for opening and closing bucket and for hoisting. For raising and lowering the boom one 30-h.p. motor is used. For moving the bridge along the dock one 75-h.p. motor in front, and two 40-h.p. motors in back are placed at the bottom of each leg. These bridges are guaranteed to make 50 round trips per hour from the hold of the boat to the storage pile. When " breaking down " a boat one of these bridges has made eighty trips and unloaded 400 tons of coal in one hour.

The control system is direct current magnetic, actuated by air. The direct current is furnished by small motor generator sets, and the air by small air compressors in each cab.

Both pneumatic and dynamic braking are used. In dynamic braking direct current from the motor-generator sets is connected to the armatures of the hoist motors with the secondaries short-circuited through resistance. This type of braking is satisfactory but requires the use of a considerable amount of additional energy.

The screening hoppers at the rear of the dock, shown in Fig. 4, empty the screenings on to the rear end of the storage pile, which is inconvenient, and some other method will probably be devised for disposing of the screenings.

The car pullers and box car loaders have been described before.

The second type of man trolley equipment is shown in Fig. 5. This type is equipped with clam shell buckets weighing 7½ tons, while the total weight of moving equipment is 40 tons.

The energy is delivered to the transformer house, shown in Fig. 7, at 13,000 volts, three-phase, and is reduced to 440 volts by three 500-kw., single-phase transformers. The current is distributed to the bridges, as shown in Fig. 7, by three conductors running on the rear elevated stationary leg. Each hoist is equipped with one 225-h.p., three-phase, 25-cycle wound rotor motor for closing and hoisting the bucket, and two 112-h.p. motors for racking.

The control is alternating current magnetic, and has thus far operated with no trouble at all. The braking is friction operated by foot levers.

The first type of man trolley equipment has been in use about two years and while considerable trouble was experienced at first, the difficulties are being overcome and satisfactory results are now assured.

The second type of man trolley equipment has been in operation only about six months so that definite conclusions as to its results cannot be drawn at this time.

SUMMARY OF COAL DOCKS

A comparison of the different types is shown in the accompanying table. While a larger number of cable car bridges are in use, these bridges are of a smaller capacity and not as much coal is handled by them.

The kilowatt-hour figures per ton of coal are approximate only, as these are liable to variation from time to time, due to the way the coal is handled. At times a larger proportion is screened than at others; also in case of fire in a coal pile it is necessary to dig out all the coal near the affected area, which increases the kilowatt-hour consumption materially.

The friction type of brake is the most reliable and economical. Dynamic braking is more expensive to operate but is satisfactory with trained operators. The operators have also tried connecting the motors directly to the alternating current line and using regenerative braking, but the drop of the bucket is too short to get satisfactory results. The alternating current magnetic control gives the least trouble and is the simplest to operate and maintain.

COMPARATIVE TABLE OF THE DIFFERENT TYPES.

Types of Equipment	No. rigs in operation	Inst. peak per ton of coal	Peak occurs while	Kw-hr. per ton of coal	Braking	Control System	Distribution System	Yearly kw-hr.	Yearly l.f. on inst. peak
Cable operated	3	119	Racking	1.09	Friction	A.C. magnetic	440 volts	980,000	8 %
Cable operated	1	129	Hoisting						
Car system	9	90	Hoisting	1.38	Friction	A.C. pneumatic	440 volts	71,424	4½%
Man trolley No. 1	6	97	Hoisting	1.76	Pneumatic	D.C. pneumatic	13,000 volts	3,258,220	6 %
Man trolley No. 2	3	85	Racking	1.50	Friction	A.C. magnetic	440 volts	1,200,000	12 %

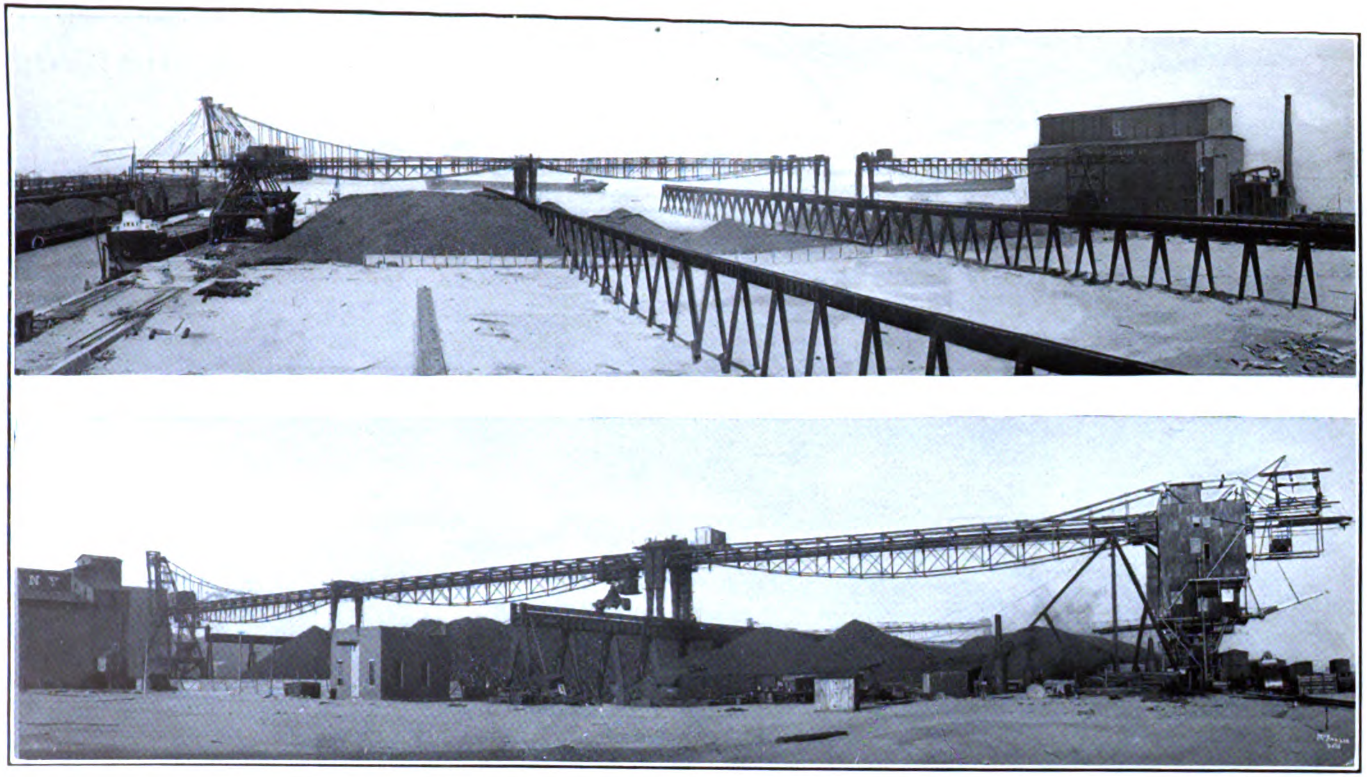

FIG. 5.—MAN TROLLEY [RYERSON AND CRANE]

Two views, showing terminal house and moving bridge with rear span detached and attached respectively: this span can be connected to either of the other bridges

PLATE X
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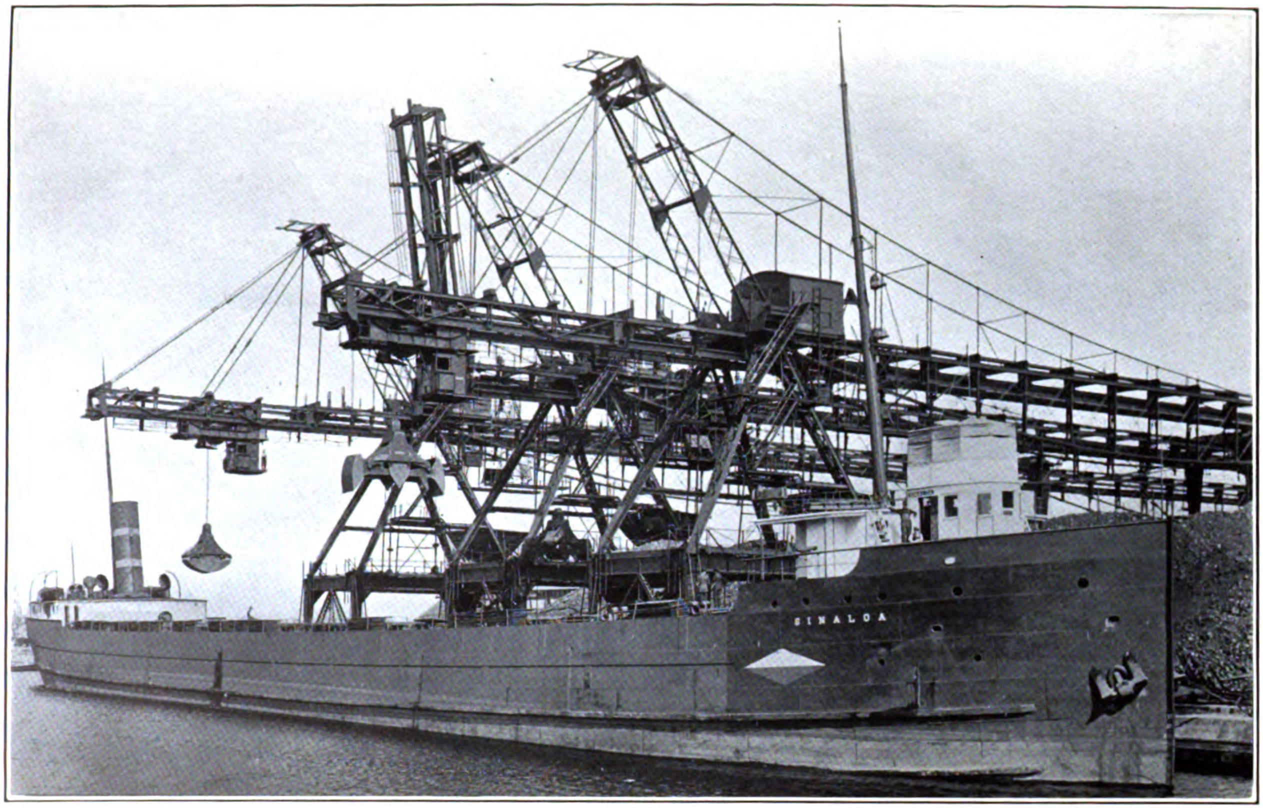

FIG. 6.—MAN TROLLEY [RYERSON AND CRANE]
Showing bridge unloading from boats—center boom raised and not working

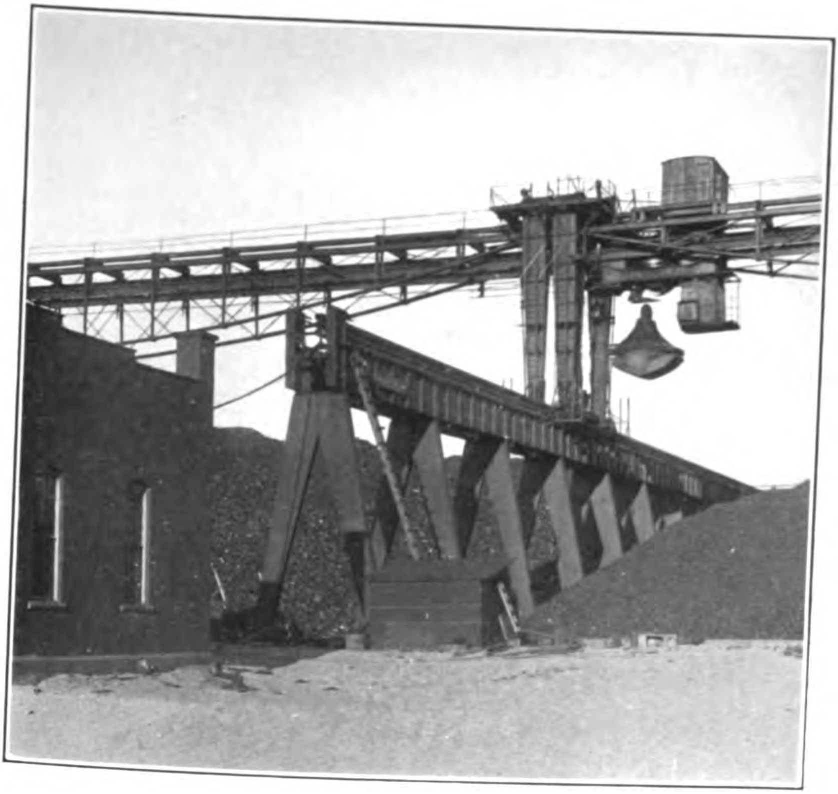

FIG. 7.—MAN TROLLEY [RYERSON AND CRANE]
Showing transformer house and method of distributing 440 volts to bridge

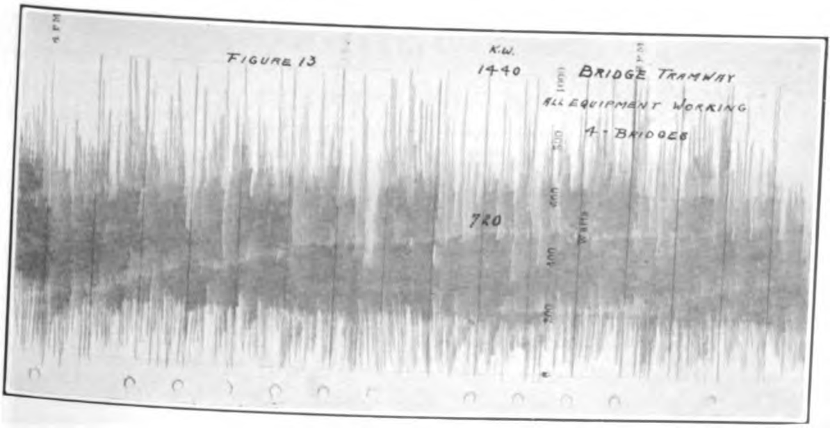

FIG. 13.—BRIDGE TRAMWAY [RYERSON AND CRANE]
All bridges working

The load factor varies on the different types, partly on account of the different equipment and partly due to the methods of handling coal on the different docks.

The 440-volt distribution is the most satisfactory from an operating standpoint for both the coal dock and central station.

The copper for distribution is a little more expensive in the 440-volt distribution. The 13,000-volt distribution, while cheaper in first cost, has given trouble due to coal dust and smoke and steam from the locomotives collecting on insulators and in wet weather causing flash overs.

The above figures are for handling bituminous coal. Anthracite coal is hoisted from boats by the same equipment and is carried into sheds by means of conveyer, belts, etc., and so does not represent a radical departure from the usual conveyer systems,

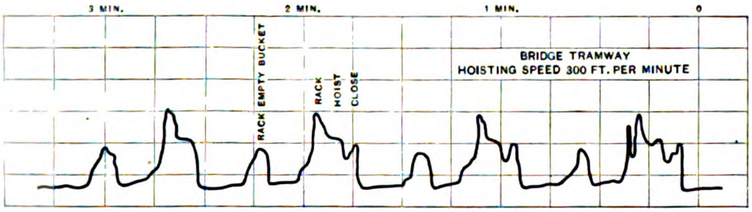

FIG. 8

The curves in Figs. 8, 9, 10, 11 and 12 were taken with a curve drawing wattmeter speeded up to give two inches per minute. The highest point on these curves is liable to an error of from four to six per cent, due to overshooting on the part of the pen, but they are sufficiently accurate to give comparative cycles of operation for the different types of equipment.

In Figs. 8 and 12, the first type of cable-operated equipment and second type of man trolley equipment, the highest peak occurs while racking, while in the other types, as shown in Figs. 9, 10 and 11, the highest peak occurs while hoisting. The load factor is so low on the coal dock load that it is important to consider the peak, either when buying power or when generating it with the company's own plants. The most advantageous design from an economical and operating standpoint would be to have the hoisting and racking peaks the same.

In the above curves it will be noted that the extreme peaks are due to the acceleration of the motors and equipment and that the actual peak, once the machinery is in motion, is 50 to 60 per cent of the above figures.

The curves in Figs. 13, 14, 15 and 16 show the daily operation of the different types of equipment, with whole docks in operation, and these are the curves on which the monthly bills are based.

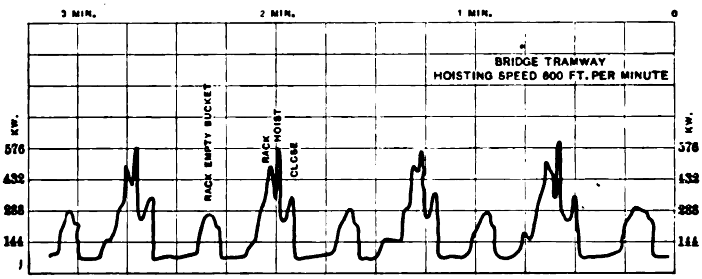

FIG. 9

Motors for use on the above work should therefor be designed for a low accelerating current and high starting torque and be especially well braced, as the excessive vibration on these towers is very severe on all the machinery.

It would be possible to design a dock with lower hoisting speeds, racking speeds, etc., which would handle the same amount of coal in a year and use current more economically, but it is necessary to unload large amounts of coal on short notice, as certain kinds of coal have a very limited movement to the lake ports and at other times, due to congestion on account of storms, etc., a large number of boats are at this port awaiting dispatch.

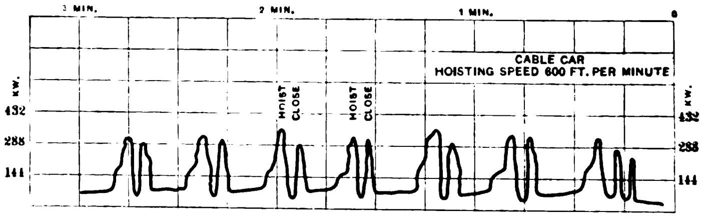

FIG. 10

During the winter months, when coal is shipped out only, the loading facilities are able to take care of from two to four times the number of cars the railroads can supply, and with smaller equipment for loading, such as is provided at the dock using cable-operated equipment, the kilowatt-hour consumption per ton of coal, and also the peak, is materially reduced.

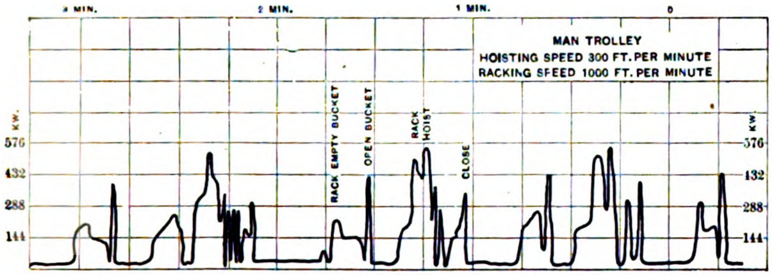

FIG. 11

One of the local coal companies operates two docks, one equipped with direct-current motors driven from its own plant, the other operated by alternating-current motors and purchased energy. The company expresses itself as seeing no difference in operating between the two methods.

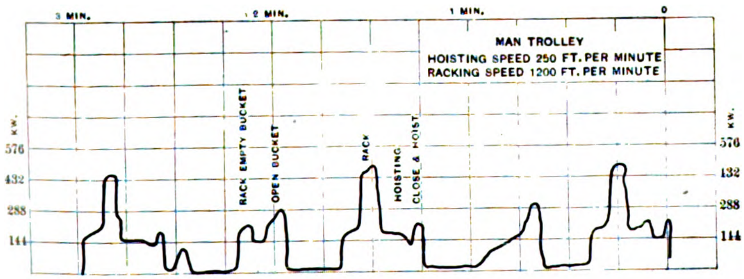

FIG. 12

In connection with its own direct-current plant it has a storage battery installed for taking care of the peaks. This year it became necessary to increase its power facilities and the following conditions were considered:

Synchronous converter using purchased energy.

Induction motor generator set using purchased energy.

Additional steam-driven units.

Low pressure turbines using exhaust steam from present engines.

Additional storage batteries.

The requirements were that the additional units must operate in parallel with the present steam driven units.

The synchronous converter using purchased energy was finally decided upon, principally on account of its low first cost and the guarantee by the manufacturer of satisfactory operation. This machine was installed last summer and has worked satisfactorily and is taking care of the peaks and relieving the engines and storage batteries from the resultant shocks, so that a decrease in maintenance cost has already been noticed. The synchronous converter is compound wound without interpoles and is run with full series field. It is placed about 150 ft. (45 m.) from the main switchboard and each side is connected to the main bus by two 1,000,000-cir. mil cables. By using one or both cables it is possible to have the converter take a smaller or larger amount of the total load.

RATES

The rates charged for coal dock service are as follows: $1.00 per month for each kilowatt of the minimum rating of the load, or " reservation charge."

$.011 per kilowatt-hour for all power used up to 70 kw-hr. for each kilowatt of rating of the load for the month for which charge is made.

$.005 for all additional power used, or " consumption charges."

The minimum rating of the load is the maximum rate at which power is used, as determined by curve-drawing meters, on the basis of the highest amount obtained from any of the following measurements:

The maximum instantaneous peak less 60 per cent discount.

The maximum one-minute peak less 50 per cent discount.

The maximum three-minute peak less 33⅓ per cent discount.

The maximum five-minute peak less no discount.

The minimum rating thus obtained is used until succeeded by a greater peak and such increased minimum rating holds until a still greater peak is obtained, and so on during the life of the contract.

A curve-drawing wattmeter is installed at each dock for obtaining the peak and watt-hour meter for obtaining the kilowatt hour consumption.

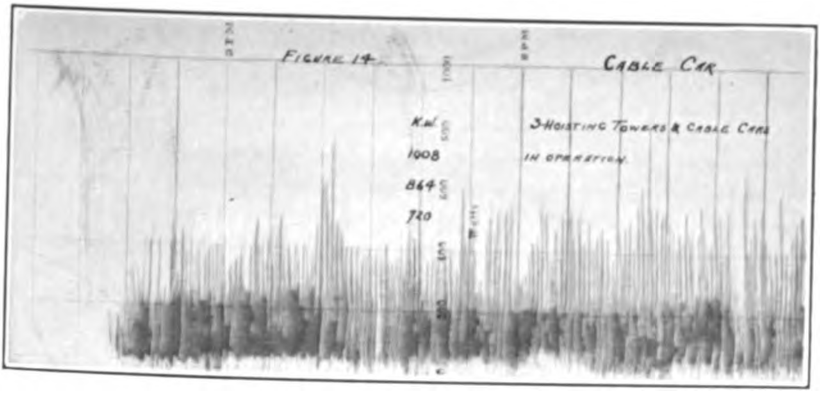

Fig. 14.—Cable Car [Ryerson and Crane]
All bridges working

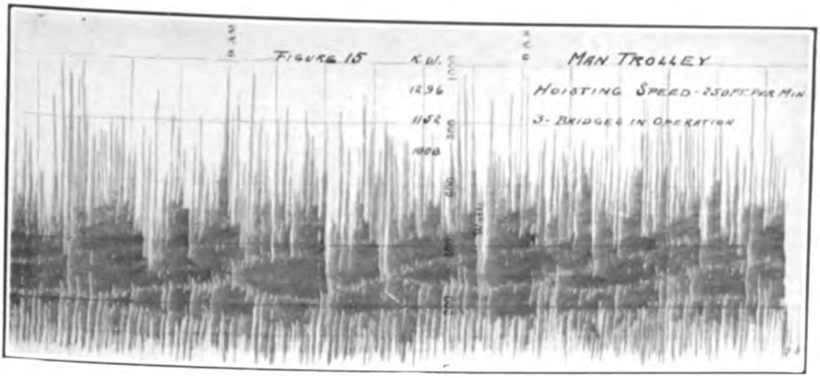

Fig. 15.—Man Trolley [Ryerson and Crane]
Two bridges, 250 ft. per min.

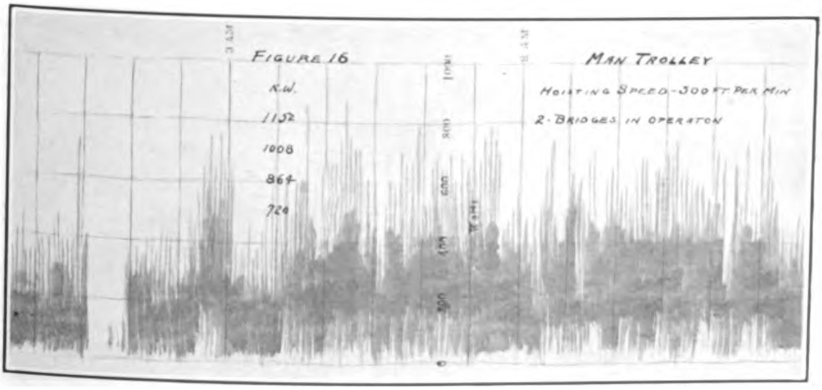

Fig. 16.—Man Trolley [Ryerson and Crane]
Three bridges, 300 ft. per min.

In coal dock service, the highest peak obtained is the maximum instantaneous peak, less 60 per cent discount, and this peak is used in determining the " reservation charge " for this class of service.

This method of charging gives a net kilowatt-hour rate varying according to the load factor, as shown in Fig. 17.

It would naturally be assumed that with a peak method of charge some form of flywheel equalizer would be installed at some of the docks. Owing to the sixty per cent discount from the maximum peak the installation of a flywheel does not offer sufficient saving to warrant the expenditure of a large sum of money for this purpose.

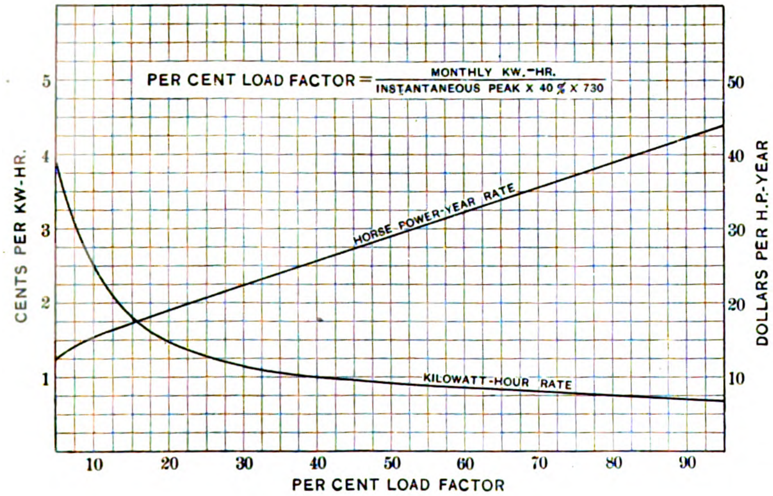

FIG. 17.—CURVE OF RATES

OPERATION FROM CENTRAL STATION

The power station is equipped with 7,500-kw. generators driven by 13,000-h.p. turbines under a head of 375 ft. (114 m.). The turbines are fed by 7 ft. (2.1 m) pipes, approximately 5,000 ft. (1524 m.) long, and a standpipe is located at the lower end of the pipe line to each pipe. Oil pressure governors and mechanically operated relief valves are installed.

With all the coal docks in operation together with the other miscellaneous load, instantaneous load changes of 5,000 kw. have been noted at the power station. With two units in operation no trouble is experienced with speed regulation, but with one unit only, the peaks cause hunting of the governor and a resultant variation of frequency of 4 per cent either side of normal has been noted.

The coal docks using the 13,000-volt catenary trolley have occasioned some trouble to the underground cable system and substation oil switches, due to short circuits. The resultant surge affects the entire distributing system owing to the sluggishness of the dock switch.

For this reason all the coal docks with this type of distribution have been placed on the same feeder and it is expected that the installation of a different type of oil switch with either a time limit relay or reactance in the trolley connections at each dock will entirely do away with this trouble.

After three years of operation the use of alternating current for this class of service has proved commercially successful and it is safe to say that the majority of new installations at this point will be of this character.

A paper presented at the Pittsburg Branch Meeting of the American Institute of Electrical Engineers, Pittsburg, Pa., January 9, 1912.

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CENTRAL STATION POWER IN COAL MINES

BY W. A. THOMAS

The increased activity of central station operators in developing markets for power makes this subject of considerable interest to electrical engineers in general and particularly to the engineers of this immediate locality.

The casual observer is doubtless inclined to believe at first thought that, with cheap fuel,—particularly of the lower and less salable grades— available at coal mines, it could not be made an attractive field for the sale of central station power, particularly where the central stations are located in cities where real estate and taxes are comparatively high. The error in such judgment lies in the fact that the coal bin and ash pile are not principal factors in the power problem, but are secondary, even with transportation added to the fuel, to the items of interest and depreciation on investment and load factor on the system.

The writer has not had opportunity to make a close study of load and diversity factors and their relation to power costs, but herein undoubtedly lies the key to the situation as affecting the interest of the central station man and the possible purchaser of central station power for coal mine operation. It is well, therefore, to inquire into the problems of the mining man and how the central station can be of use in their solution.

The principal elements are cost of production, reliability of operation and decreased investment. The primary operations involved in the production of coal are undercutting, transporting and hoisting. The secondary operations, as far as power requirements are concerned, are ventilation, drainage or pumping, operation of tipple and other outside machinery, and a small amount of lighting. Sometimes, however, the question of hoisting is eliminated where drift entries occur, and on the other hand the pumping sometimes becomes one of the primary operations.

It is not the intention of this paper to discuss the relative advantages of electric drive over and above other methods of operation, although as regards cutting, it is interesting to note that the electric coal cutter is estimated as reducing the cost of production of coal from 10 to 12 cents per ton. This operation is one offering a very good load for power as it is fairly continuous throughout the day hours up to 3 or 4 o'clock in the afternoon, and very often forms a fairly desirable night load from 6 o'clock until midnight. It is probable that a more universal electrification of mines will show considerable increase in the use of power for this purpose, as a great many mines which have animal haulage at the present time are using hand methods for undercutting the coal. Statistics show that in one state alone, from 1905 to 1909, there was over 200 per cent increase in the number of electric cutting machines in service, as against something like 30 per cent increase in the number of air cutting machines.

In connection with cutting operations, there are installations where compressed air is in use and will doubtless be perpetuated owing to local conditions or the cost of the installation. It is very probable that in installations of this kind low central station rates for the supply of power will show economy in driving the air compressors with electric motors. This is the practice of the Berwind-White Coal Mining Company, which generates its own power in a central station.

As regards the haulage problem, it is too well known that electricity is superior to any other form of haulage for a discussion of its merits in a paper of this kind. It is recognized that in certain mines the danger of gas explosions is too great to introduce an electric locomotive using trolley for collecting the current. In this case, probably the safest form of mechanical haulage is the compressed air locomotive and the compressor drive again forms a possible market for electric power and makes an extremely desirable load.

The combined problems of cutting and hauling form the nucleus around which an electric installation can be made, and while it is proposed to discuss the question of installation costs a little later, it should be noted that these two problems are usually considered at one time in determining upon such improvements. A number of factors enter into the question of such improvements and where the older mines are not equipped with mechanical haulage, it is necessary in most cases to relay the track with heavier rails to stand the weight of the locomotive, which must necessarily be heavier than the cars in order to offer sufficient draw-bar pull to permit of bunching cars into trains and cut down the labor attendant upon the old system.

The original installation for animal haulage in the older mines is usually of narrow gauge to permit of easier handling of the cars, and the rails are usually light in weight, as the single loaded cars were the heaviest burden which the tracks had to bear. In most cases these older mines cannot be improved by widening the gauge, owing to the haulage roads being "gobbed" up along the sides with waste rock and slate, a certain amount of which is always present in normal mining operations.

After a mine has assumed commercial proportions with any considerable development away from the entry or shaft, it is seldom difficult to demonstrate the possible savings in the use of electric haulage. In fact, it becomes imperative that some form of mechanical haulage be employed, as the capacity of a gangway is limited with animal haulage. In the state of Pennsylvania, unquestionably 75 per cent of the coal is so handled, although in some states it is as low as 45 per cent. These figures have reference to main haulage only and in many cases horses or mules are used to collect the cars to sidings where electric, steam or compressed air locomotives haul them to the point of delivery. There is a large field for gathering locomotives to supplant the animals for this purpose and considerable progress is being made in this direction.

The question of pumping or drainage is oftentimes of great importance, as this load is steady and often heavy. The use of electricity for this operation in all kinds of mines is most advantageous and in nearly all cases, pumping by electricity is much more economical, more flexible and more reliable than steam or compressed air. The use of hot steam pipes in a timbered shaft or gangway is objectionable on account of the rapidity with which it hastens the decay of the timbers.

In shaft mines the most serious problem in the application of electricity is that of hoisting. There seems to be more or less predjudice among coal mining men in this country against the the electric hoist, whereas in Europe the principal mines are usually so equipped. Probably one of the most logical reasons for this is a lack of knowledge of their operation, and back of that is the fact that the coal in most American mines is so low in its commercial value that it is hard to justify the capitalization of the electric hoist where it involves the building of a plant to supply power for the hoist, since the combined cost is necessarily more than that of the boiler plant and steam hoist.

With central station energy available, however, we have a different set of conditions and it is my belief that its introduction will open up the hoisting proposition very rapidly. In the past, one of the chief difficulties has been the necessity of converting to direct current for hoisting purposes, but this is no longer true, since the more complete development of the alternating-current hoist motor with the necessary control. The use of straight alternating-current hoist motors up to 500 h.p. capacity is now an accomplished fact.

One important feature of the hoisting problem is the extremely wide variation in the power demand and the influence of the extreme hoisting peaks upon the transmission line, or the entire station if it be a relatively small one. With large stations, however, the influence is relatively less and the use of motors up to 500 h.p. capacity does not prove so objectionable, although sometimes it is found practical to equalize the load if the conditions are such that peak loads are penalized. Various systems have been devised to overcome this fluctuation, among which are the storage battery in the case of the direct current hoist and the use of the reversing a-c.-d-c. motor generator set and storage battery in the case of the alternating-current hoist. Investment and maintenance charges are very heavy in both of these systems.

Another system used in connection with the use of alternating-current hoist, consists of a synchronous converter floating on the line and connected across the direct-current end of the converter is a shunt wound motor, on which is mounted a flywheel which acts in the capacity of a mechanical storage battery, operating normally on weakened field and at maximum speed. When the demand from the hoist and other loads combined exceeds a predetermined value, a line relay operates to strengthen the flywheel motor field, bringing its counter e.m.f. up sufficiently to feed back through the converter to supply the excess demand for power. After the passing of the peak, the line relay acts to weaken the motor field and restore energy to the flywheel. This system is an improvement over the use of storage batteries, particularly as to maintenance and efficiency. All of these systems still involve the use of rheostatic control in one of its various forms and the maintenance and repairs of heavy contacts on large hoists.

Probably the most promising equipment, and the one now being most universally installed, is known as the flywheel equalizer system. A complete equipment of this kind consists of a direct-current shunt wound motor driving the hoist and a motor generator set, the direct-current generator being connected to the hoist motor and the alternating-current motor to the supply system. Coupled or connected to the motor generator set is a flywheel, the function of which is to give out energy when the load on the generator exceeds the average value, and to absorb energy when the load falls below the average.

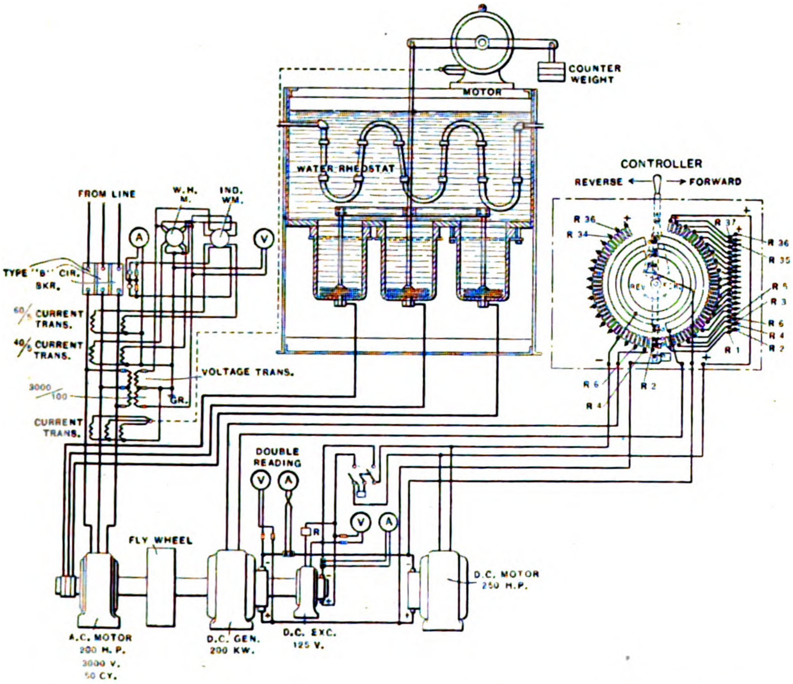

Fig. 1.—Diagram of Connections for Equalizer System for 250-h.p. Hoist Motor.

The hoist motor is separately excited, the excitation not being varied during the operation. The direct-current generator is also separately excited, the armature voltage being controlled by the field strength from full value in one direction down through zero to full value in the opposite direction. To reverse the hoist motor, the field of the generator is reversed, the speed of the hoist motor being practically in proportion to the direct-current generator voltage and being controlled by varying the field strength of the generator, with which any speed desired may be obtained. If, when the motor is running, the field of the generator is weakened so that its voltage falls below the counter e.m.f. of the motor, the latter will act as a generator and return energy to the motor generator set, which if below full speed, stores energy in the flywheel. This is used instead of a mechanical brake to stop the hoist. It is also used in lowering the men and materials into the mine by pumping back through the motor generator set to the line, if the energy so derived is sufficient to drive the set slightly above synchronous speed.

In order to equalize the input to the equipment, means are provided for automatically varying the speed of the set. In this connection, a direct current motor is sometimes used for driving the set and the speed is then varied by regulating the motor field. In a majority of cases, however, the alternating current motor is used and the speed is varied by regulating the resistance of the alternating-current motor rotor circuit, wound rotor type of motors being used for this purpose.

The regulator is arranged so as to introduce resistance into the circuit when the demand reaches the predetermined value and to keep on adding it as long as the demand stays above this value until the flywheel set is slowed down to the practical limit at which it will pay to use this stored energy, and in reverse manner the regulator automatically cuts out the resistance when the load drops and brings the flywheel set back up to normal speed, restoring energy to the flywheel.

In order to provide for the excitation of the generator and hoist motor, an exciter is usually coupled to the motor generator set. As the speed of the set is continually varying, a voltage regulator is provided for keeping the voltage of the exciter constant.

For controlling the speed of the motor generator set, an automatic regulator is used and as offered by at least one manufacturer, is of the liquid type. This type of regulator has a number of advantages over the arrangement using magnetic switches for cutting the resistance in and out of the rotor circuit, the principal one being greater simplicity and better regulation. One of the most notable installations of this type of hoist is now being installed by the Cleveland Cliffs Iron Company in its Michigan iron mines.

This equipment covers two hoists, one of 500 h.p. for hoisting ore, and one of 200 h.p. for hoisting men and lowering materials. The operation of the regulator on this installation is very simple, the three phases of the rotor winding being connected to three stationary plates in separate earthenware pots. Above these plates are the movable electrodes which are connected together. The movement of these electrodes is controlled by an induction motor, this motor being supplied with current through series transformers in the line feeding the motor generator set. The current flowing in the motor is proportional to that in the main line and the torque of the regulator motor varies as the square of this current. The electrodes of the regulator are attached to an arm coupled to the motor shaft and are counterweighted on the other end of this arm beyond the motor shaft. Under normal conditions the counter-weight does not quite balance the weight of the electrodes. At the full load current in the main line, the torque of the regulator motor, which tends to separate the electrodes, will be sufficient to bring the whole of the moving parts to a state of equilibrium. Any increase in the current in the main line will cause the torque on the regulator motor to increase rapidly and the electrodes will be separated, thereby introducing resistance into the rotor circuit, thus reducing the speed tendency of the motor generator set with the result that the flywheel gives up a portion of its stored energy. If the current in the main line then drops below the value for which the regulator is set, the electrodes will then come closer together and the speed of the set will be increased and energy restored to the flywheel. The regulator in this way tends to maintain the input to the equipment at a constant value.

The electrodes are made of iron and the tank is filled with a solution of carbonate of soda (common washing soda). In the lower portion of the tank, cooling coils can be provided, through which water can be circulated and excessive evaporation of the solution is thereby obviated. The value for which the regulator is set can readily be changed by altering the amount of counterweight, the addition of more weight reducing the current at which the regulator will operate, as the torque required from the motor will be correspondingly less.

The field controller for the direct-current generator is so arranged that the field circuit is never open and in this point in particular the control is ideal. When the controller is in the "off" position, the field is connected across the armature terminals in such a way as to oppose the residual magnetism and any potential generated due to residual magnetism causes current to flow in the field winding, which will tend to build up the field in the opposite direction, thereby killing the residual field. The advantage of this arrangement is that when the hoist is at rest there will be no current flowing. Altogether this system promises much for the solution of the hoisting problem and the equalization of a very intermittent load, so as to make it commercially desirable for central station power supply.

Additional installations of this type of hoisting equipment in this country are the Hecla Mining Company at Burke, Idaho; the Calumet & Arizona Mining Company in Arizona; the Winona Copper Company in Michigan, and some six or seven similar installations in Mexico, notably those in the mines of the El Oro Mining & Railway Co.

It is recognized that this development is most advantageous where fuel costs are high, and consequently the principal installations up to this time have been made in metal mines. This solution of the heavy hoisting problem is nevertheless one of promise and worthy of careful study as applied to coal mining.

In the complete electrification of existing mines having boilers and steam hoists, a suggestion is now being investigated as to the practicability of making such modifications in the steam hoist as are necessary to operate same with compressed air, using one of the boilers as a receiver, and if practical, a re-heater as well, and installing an electrically driven air compressor of such capacity as to work practically all of the time when steady hoisting occurs, the boiler being used to store air while the hoist is out of service, and to supply the excess demand over and above the capacity of the compressor when hoisting. No definite conclusions have been reached as regards either the economy or practicability of this suggestion but it offers a possible simple solution of the perplexing question of what to do with a steam hoist which is sometimes not readily convertible to electric drive.

The ventilation problem is in no way difficult, although we have met with a great deal of prejudice against the use of motors for this purpose as well, but convincing trials have brought mining men to a general use of motors for this application. The Pittsburgh Coal Company is quoted as having established records for continuity of service of electrically-driven fans, better than that obtained with steam engines. The load for this purpose is an attractive application from a power standpoint, as the fan is usually required both day and night.

The other secondary operations are considerably varied but comparatively simple in point of application, and combine to make the mine load very attractive to the central station which is so situated as to be able to serve this field. These problems are greatly simplified if the installation is a new one, in which there is no necessity of considering the adaptation of electric drive to existing machinery, and in which we do not have to consider converting an old power house into a substation. The principal market for power, however, for present consideration, is the electrification of the existing mines, the new installations being only incidental to the general situation.

The power consumption in the electrical operation of coal mines varies widely with different local conditions and cannot be accurately predetermined from general data, but requires careful local study, as a wet mine which is not self-draining will require considerable power for pumping purposes, whereas a self-draining mine with water level haulage will be relatively light in its power consumption for both transportation and drainage. The load they get is fairly uniform. In cases of a slope or shaft hoist, additional power is required as against the drift entry.

A number of tests have been made which show as low as 1.22 kw-hr., and as high as 3½ kw-hr. per ton of coal mined with varying conditions. In some cases the service was mixed, using both steam and electricity. In others, rope haulage with steam engines was used. One or two specific cases are illustrated as concrete applications, with the corresponding results. As a general proposition, it is estimated that the power requirements will vary in completely electrically-operated plants from 1½ to 3½ kw-hr., depending upon the above mentioned varying conditions, and in the same mine, the requirements will vary with meteoric conditions where a considerable amount of pumping is involved.

MINE NO. 3

Slope-Capacity—35,000 tons per month.
Output—15,000 " " "

One 10-h.p. fan
Two 20-h.p. fans
One 20-h.p. pump
One 2½-h.p. pump
Three 10-h.p. pumps

Four 25-h.p. cutting machines.
One 30-h.p. cutting machines.
One 7½-h.p. hoist
One 5-h.p. air compressor
One 5-h.p. shop motor.

Two 80-h.p. Locomotives
Two 30-h.p. Locomotives
Total—107½ h.p. continuous rating
250 -h.p. intermittent rating
Maximum demand =230 h.p.
1.22 kw-hr. per ton of coal

COMBINED MINING AND COKING PLANT NO. 6

75 Ovens-capacity 5000 tons per month

One	100 kw. motor generator set
One	100 h.p. alternating current fan motor
One	15 h.p. direct current pump motor
One	25 h.p. direct current coke conveyor and loader
One	5 h.p. direct current leveler rake
One	25 h.p. direct current leveler ram
One	40 h.p. direct current coke pusher
Two	35 h.p. direct current locomotive motors
One	25 h.p. direct current larry

Seven months operation 34,000 tons of coke, 110,000 kw-hr. or 3.2 kw-hr. per ton of coke.

When we consider the vast tonnage of coal in the many localities, we begin to appreciate the possibilities of a power market for its production. Among the most prominent installations of the character described are those on the lines of the West Penn. Railways Company in the Connellsville Pa. district, with which many of the local engineers are familiar. The district served in this case involves some of the worst conditions to be met in the way of drainage and hoisting. I feel safe in expressing the opinion, however, that the installations have proved both profitable to the power company and economical to the mining companies.

Considerable activity is evidenced at the present time in other fields, notably the installation now being made in West Virginia by the Appalachian Power Company, which is developing a hydroelectric plant to furnish power in the Pocahontas coal fields. The Pennsylvania Central Power Company, of Altoona has recently authorized the construction of something like 75 miles of transmission line to cover the Cambria County field.

One extremely advantageous factor in considering this proposition is the fact that with central station energy available, the investment for the small mine is greatly reduced. An isolated plant costing from $12,000 to $15,000 will in many cases be required where a $5,000 substation will do the work. In some cases it has been found advantageous for the central station to put in the substation machinery and operate it on a rental basis, or sell power converted to low voltage or direct current at the bus bars. This is the extreme proposition where the mining companies are not sufficiently capitalized to make the improvements and is comparable with the practice of renting simple fixtures to merchants for their lightning contracts, which has also proved advantageous in many cases.

The distribution of the mine load is such as to prove most desirable, as the principal load comes on at, or slightly before, 7 o'clock in the morning and as a rule falls off to a low value between 3 and 4 o'clock in the afternoon, at which time the lighting load picks up during the winter months. It is true that in some cases a comparatively small load comes on again at 6 o'clock and carries through the peak lighting period, but is not of such proportion as to seriously influence the station capacity.

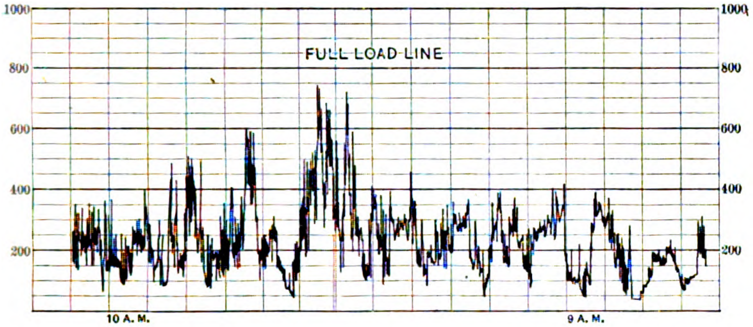

FIG. 2.—DAY LOAD ON 800-AMPERE MINE PLANT

The accompanying charts show the general character of the load and while wide fluctuations occur, they will in the main balance up fairly well where a considerable number of installations are centralized on one plant.

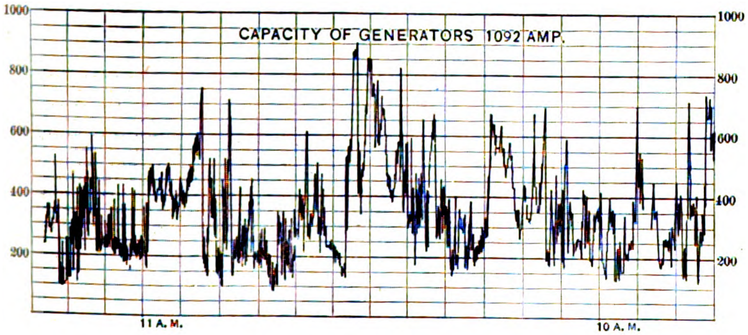

FIG. 3.—DAY LOAD ON 1092-AMPERE MINE PLANT

The question of power contracts calls forth considerable discussion and it is beginning to be recognized that in handling the average mine operator, the same methods cannot always be employed as in handling the industrial plant or the local user of a comparatively small amount of power. The mine operator figures entirely on results and the mine superintendent has ever in mind the cost per ton of producing coal. A serious mistake has been made in one or two cases in putting forth too prominently to the mine operator the value of the central station's readiness to serve. A careful analysis and line of reasoning will doubtless bring the mine operator and central station man together, provided the mine operator realizes that he himself is put to a considerable constant expense if his own plant is shut down, and is not producing energy. Of this feature, however, he often loses sight, owing to the fact that he has taken care of the cost of the plant by an appropriation, and the interest and depreciation are not charged up against the cost of coal.

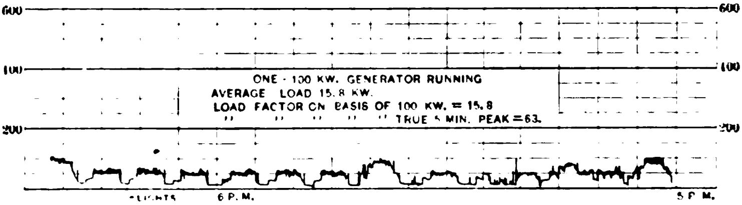

FIG. 4.—EVENING LOAD ON 400-AMPERE MINE PLANT

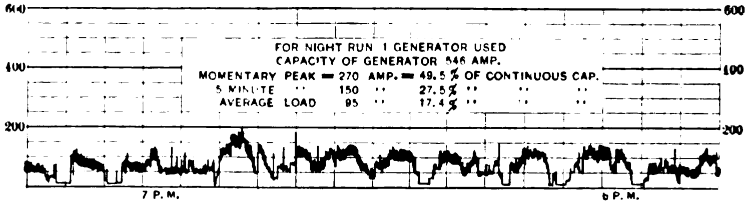

FIG. 5.—EVENING LOAD ON 600-AMPERE MINE PLANT

In talking about the readiness to serve, due consideration should be given to this point and the operator will realize that a certain amount of income is due the central station for the investment necessary to supply power at his demand. On the other hand, the central station solicitor or contract agent should figure carefully the approximate cost that the mine operator must sustain in shutting down his own plant, and it can fairly easily be shown that the minimum charge involved, be it in the form of minimum power consumption or a fixed rate per kilowatt per year, does not much more than offset the real expense represented in the customer's plant when it is standing idle.

A careful analysis of several typical small mining plants shows the average working days per month to be from 15 to 20. It shows the average load factor during an eight hour day to be slightly over 50 per cent, based on a ratio of average consumption to maximum peak of five minutes duration, and does not take into account the actual capacity of the generators or the momentary swing of the ammeter as indicated in one of the accompanying charts.

Careful tests on four typical plants in Ohio show the following:

Average cost of power	2.485	cents per kw-hr.
Cost for substation equipment, less salvage	.124	" " " "
Common cost for either source . .	.7	" " " "
Central station rate to balance against present cost	1.661	" " " "
Average power consumption. . .	47,700	kw-hr.
Average kw-hr. per ton coal. . .	2.49	

As previously inferred, with reference to the discussion of fixed charges or minimum demand, the continuity of power service and its use must be considered. It is evident, therefore that some form of contract must be considered which will protect the central station against the investment of building the lines and installing sufficient machinery to take care of the maximum demands, if the conditions become abnormal as regards shutting down for a considerable length of time. As considering the relative merits of a fixed charge per kilowatt per year as against a fixed rate per kilowatt-hour with a minimum charge, there are points in favor of both methods. Considering a fixed charge corresponding to the substation capacity, an analysis shows that the approximate cost per horse power installed in the case of the isolated station where it is necessary to keep a fireman at the boiler plant, who can also run the engines where electrical power is used for pumping and other purposes, is approximately $1 per month, based on the total horse power installed in the isolated plant. In establishing a corresponding rate to protect the central station against shut down, it therefore, seems logical to place this at approximately $1.25 per month per kilowatt of substation capacity. This is sometimes reckoned on the total continuous kilowatt capacity of the station, but perhaps a more equitable arrangement as compared with the central station demand is that of taking a maximum five-minute peak or some other form of record which will show a maximum demand of the substation.

In conjunction with this fixed rate of $1.25 per month per kilowatt installed, a relatively lower price per kilowatt-hour is established to protect against the maximum consumption when power is used steadily. This rate, of course, must necessarily vary with local conditions, cases having been known as low as ½ cent per kw-hr. in conjunction with the fixed charge of $1.25 per kilowatt installed.

In the case of the four Ohio plants, the average capacity was 250 kilowatt per station. The average cost per month, say at 1.5 cents per kw-hr., would be $715.50. To arrive at the same result with a fixed charge of $1.25 per kilowatt per month, we would have a fixed cost of $312.50 and a power rate of 0.846 cent per kw-hr.

In studying the accompanying curves, it should be noted that several of these installations served by one power house do not represent nearly so high a kilowatt capacity installed in the central station for this service as proves to be the case with the isolated plant, as for instance, it is shown that the maximum demand in one or two of the cases does not reach the total station capacity installed. As a rough estimate we figure that the central station capacity for the mine service will not exceed 45 per cent of the total aggregate maximum peaks represented in the various sub-stations served.

A further careful analysis of the character of this load and the fact that a considerable amount of profitable load can be picked up in the small towns adjacent to the mining operations, makes this a particularly attractive field for the supply of central station power, even on the basis of reduced cost of operation to the mine manager.

In the matter of reliability of service, the up-to-date central station has shown results which the isolated station cannot often meet in the way of continuity of service. A secondary consideration which interests the mine operator is the reduction in the number of men required with central station service. We feel safe in predicting that the next five years will see a large percentage of our coal mines operated from public service central station power.

A paper to be presented at the 269th meeting of the American Institute of Electrical Engineers, New York, March 8, 1912.

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SOME PROBLEMS OF HIGH-VOLTAGE TRANSMISSIONS

BY CHARLES P. STEINMETZ

For a considerable time the voltage of long distance transmissions was limited by the line insulator. Until a few years ago, the transmission line insulator was the same pin type as used in telegraph and telephone lines, differing only by its larger size, by the replacement of glass by porcelain, and by the addition of a few more petticoats, but no radical change had occurred, until the limit of this type was reached at 30,000 to 40,000 volts—with a few 60,000 volt lines of questionable reliability.

The development of the suspension type of insulator practically removed this limitation. By breaking up the potential difference in a series of successive steps of moderate voltage, by the use of a series of insulating disks between line and ground, it became possible to insulate lines for voltages of 100,000 to 200,000 with a margin of safety greater than that of most of the 40,000 volt lines of old. In such steel tower lines with suspension insulators, even direct lightning strokes may sometimes reach the line without destroying its insulation, and the problem of line insulation thus appeared solved.

However, at extremely high voltages, even the suspension type of insulator must finally find its limitation due to the unequal voltage distribution between the successive insulating disks. With a number of equal insulating disks sharing the voltage between line and ground, the potential difference across the insulators nearest the line is higher, and the potential difference across the insulators nearest the ground is lower, than the average potential difference per insulator, the more so, the greater the number of insulator disks. Thus the flash over voltage of a string of *n* insulator disks is not *n* times that of one disk, but less, and the more so, the greater *n* and finally a point is reached where a further increase of the number of insulator disks does not further increase the flash over voltage. The reason for this is that the potential difference across each insulator disk is proportional to the current which passes the insulator (as capacity current or displacement current, and as dielectric energy and leakage current—the latter negligible except in wet weather). Each insulator disk, however, carries its own capacity current plus all the capacity currents against ground of the conductors joining the insulator disks, between the insulator disk under consideration, and the ground, at their respective fractional voltage. Thus the insulator disk nearest ground carries only its own capacity current while that nearest the line carries its own capacity current plus the capacity currents against ground of the entire string of insulators, hence the latter carries a larger current, and thereby absorbs a larger potential difference. The string of insulators represents a circuit containing distributed series capacity—the capacity between the two sides of each insulator disk,— and distributed shunt capacity—the capacity of the connection between the disks, against ground. The general equations of such a circuit of distributed shunt and series capacity, applied to the multigap lightning arrester, have been given in the TRANSACTIONS.

This effect is the more marked, the higher the frequency, and may lead to the puncture of insulators at transient voltages below the normal circuit voltage.

From this it appears that the use of a large number of small insulator disks is uneconomical at very high voltages, and a few large disks of high disruptive strength preferable.

To extend the insulating possibilities of the suspension insulator type far beyond the voltages now contemplated, therefore requires a grading of the insulator disks in their capacity, so that the disk nearest the line has the highest, that nearest the ground the lowest capacity, or the addition of capacity at the surface of the insulator disks, in proportion to their distance from the ground. The capacities of the successive insulators of a series should be proportioned so that the product of the capacity and the total displacement current (against ground and across insulator) of each insulator disk is proportional to its disruptive strength.

However, this " multigap effect " of the suspension insulator type becomes of serious moment only at voltages beyond those contemplated at present.

More serious at present is, that we have reached transmission voltages at which the air begins to fail as insulator, and direct escape of electric energy into the air begins, as corona.

This is at present the most serious limitation of transmission voltages. This led to the study of the law of corona, and the investigation is still being continued. The voltage at which a serious loss of power by corona begins depends on the size of conductor, the conductor spacing and the air density.[1] In proposed high voltage transmission lines—above 80,000 volts—an investigation of the line conditions regarding probable corona loss becomes necessary. By the use of large aluminum conductors, possibly even with separate tower lines for each phase—to get very great distance between the phase conductors—we may be able to reach a quarter million volts as transmission voltage, and possibly still higher voltages by special designs of the line conductor, of which various forms have been proposed.

With the development of the grounded steel tower line construction with suspension insulators of high disruptive strength, with the grounded overhead wires protecting the line against the entrance of severe lightning disturbances, and the aluminum cell lightning arrester protecting the stations, atmospheric lightning has practically ceased to be a formidable enemy of long distance transmission; practically complete protection against atmospheric lightning can be afforded and where lightning disturbances damage the transmission line, the ultimate cause is usually either faulty or cheap line construction—usually the latter.

Protection against atmospheric lightning thus can not be considered any more as an engineering problem, but is rather an economic question as to how far the value of the protected apparatus, and of the continuity of service, warrants the cost of lightning protective apparatus.

At the lower transmission voltages used before the development of the suspension insulator, the line was the weakest link of the transmission system, but it was believed that transformers could be built of any size and for any voltage.

At 100,000 volts and over a phenomenon makes itself felt, especially in large transformers, which is negligible at lower voltage: the distributed capacity of the high voltage transformer winding.

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[1] F. W. Peek, Jr., " The Law of Corona & Dielectric Strength of Air," PROCEEDINGS A. I. E. E., July 1911, p. 1485

At lower voltages, the transformer capacity is negligible, and the transformer thus an inductive apparatus, and as such impervious to all high frequency disturbances, such as traveling waves, impulses, stationary oscillations, etc. High frequency currents can not enter the transformer, but produce high voltage between the end turns, protection against which is given by the high insulation of the end turns of the transformer, which has been used now for some years. Or the high frequency disturbance, originating in the line, is entirely kept away from the transformer by the interposition of an inductance—a choke coil—between line and transformer.

At very high voltage the electrostatic capacity of the transformer becomes appreciable, and the high potential coil of the transformer then represents a circuit containing distributed capacity, inductance, resistance and conductance, just as a transmission line.

The high potential coil of a transformer differs materially from the transmission line in its constants. In the transformer the inductance is much higher, the capacity lower, than in the transmission line; the resistance is lower, and the conductance low, though not negligible: it represents the energy component of the capacity current, and is due to the dielectric losses in the insulating material of the transformer.

The results of this difference in the constants is, that transformer oscillations are higher in voltage and lower in current, and of lesser attenuation, that is, die out at a slower rate, than line oscillations, and cumulative oscillations—that is, oscillations of increasing amplitude—are more liable to occur in transformers than in transmission lines.[2]

The high voltage transformer thus must be considered as a circuit, capable of oscillating, just as a transmission line. That is, high frequency oscillations may originate in the high potential coil of the transformer, or oscillations originating in the transmission line may enter the transformer, and then, in passing over the transition point from line to transformer, increase in voltage while decreasing in current, by the transformation ratio of the transition point, as discussed in previous papers.

The danger to which a transformer is exposed by high frequency disturbances from the transmission line, then, is not limited to the end turns only, but damage may be done anywhere inside of the transformer, wherever a wave crest forms—which depends on the frequency of the disturbance—and such destruction of an inside transformer coil by outside disturbances is not infrequent.

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[2] Oscillographic reproduction of such cumulative transformer oscillation I have given in "Electric Discharges, Waves and Impulses," page 99.

Inductance interposed between line and transformer then becomes a source of danger: while it keeps line disturbances out of the transformer, it also reflects disturbances which originate in the transformer, back into it, and thereby increases their voltage and their destructiveness. It thus becomes necessary to add to the inductance (the choke coil) a device which bypasses disturbances which come from the transformer, but does not allow line disturbances to pass into the transformer.

This leads into the field of protection against the phenomena of high frequency disturbances, which now are the most serious, since, in the aluminum cell, a practically complete protection against transient high voltage has been developed, and which, with the increasing size of electric systems, are a constantly increasing source of danger, to high voltage overhead transmission systems as well as underground cable systems.

In high voltage long distance transmission lines of 150 miles or more, the capacity current of the line becomes considerable, and may, especially in 60 cycle systems, reach values higher than the full load current. Even then, however, the capacity current is not as serious as may be expected, and its main objection is, that it uses up generator capacity, that is, loads the generators with current which represents no power. Since it is due to shunted capacity, it may be compensated for by shunted inductance, that is, by connecting reactive coils of sufficient size permanently between the lines. This has frequently been proposed, and occasionally done.

Far more serious is the impairment of voltage regulation, incident to very long transmission lines. Assuming constant voltage at the generator terminals, the voltage at the receiving end of the line varies considerably between no load and full load—especially inductive load. Shunted reactance does not eliminate this, but while it reduces the no-load voltage by compensating for the capacity current and so eliminating the voltage rise due to this leading current, it lowers the full load voltage and so leaves practically the same voltage drop between no load and full load. A line of quarter wave length—800 miles with 60 cycles, 1900 miles with 25 cycles—transforms from constant potential to constant current. Hence, with constant voltage at the generator end, the voltage at the receiving end would rise to infinity at no load—that is, in practice, would be limited only by the resistance drop of the capacity current—and voltage regulation thus would be absent. Long before this condition is reached, voltage regulation is materially impaired. This phenomenon is most serious in the case of a short circuit on a system fed by the transmission, when the circuit breakers at the end of the line open; in this case the load suddenly changes from overload to no load; the turbines, relieved of their load, momentarily speed up and increase the generator voltage; the capacity current of the line reacting to magnetize the generator field still further increases the generator voltage, and as at constant generator voltage the change from full load to no load would cause a considerable voltage rise, with the increase of the generator voltage, this voltage rise at the receiving end of the line may reach 50 to 75% and more. This excess voltage is not a transient voltage, but is dynamic, and thus can not be discharged by any protective device of necessarily limited energy discharge capacity, but can only be lowered by consuming power or lagging current, and even aluminum cells in this case, if not instantly relieved, are destroyed.

The most effective way of protecting against this sudden rise of dynamic voltage when the circuit breakers at the receiving end of the line open seems to be, not to open the circuit entirely, but arranging it so that an inductive load is thrown into circuit by the opening of the circuit breakers, sufficient to keep the voltage down. Various ways exist of accomplishing this result.

The long debated question, whether grounded Y or isolated Δ connection is preferable in high voltage long distance transmission lines, seems to approach settlement in favor of isolated Δ. The isolated Δ has the advantage that a ground on one of the lines as a broken insulator, etc., does not cause a short circuit, and so permits continuing the operation of the system, thus giving greater reliability of service. However, if the ground is an arcing ground—as is usually the case—it produces a continuous high frequency disturbance, and this is liable to destroy apparatus, often very rapidly. As a result, this advantage of the isolated Δ could usually not be realized, but it was a question between a short circuit and shut down—with grounded Y—or the possibility (or probability) of damage to apparatus and thus finally also a shut down, by the arcing ground in the isolated Δ. With the development of protective devices which immediately eliminate an arcing ground by converting it into a permanent ground[3] this objection to the isolated Δ connection was eliminated.

A problem of long distance transmission, which requires solution, is the control of branch circuits. Very often it may be desirable to supply a moderate amount of power from a high voltage transmission line by a branch line of moderate length, and a considerable total load may be secured by such local supply from a transmission line. However, if the branch lines are connected directly to the main line, any accident in a branch line involves the entire transmission system, and the branch lines must be constructed with the same high insulation strength, and the same protective devices and controlling devices as the main line. This is economically not feasible with smaller demands of power. Equally uneconomical is the installation of a transformer substation at the branching point, for the operation of the branch line at lower voltage. This makes it desirable to develop some power limiting or localizing device at the branching point, such as would not interfere with the supply of the power demanded in the branch circuit, but would localize this circuit so that an accident, as a short circuit or ground on the branch line, would not seriously affect the main transmission system, and thereby would permit a cheaper construction of the branch line, more in correspondence with the smaller amount of power supplied by it. For this purpose a suitable form of power limiting reactance would be used.

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[3] See paper by Prof. E. E. F. Creighton: "Protection of Transmission Lines," PROCEEDINGS A. I. E. E., March, 1911, p. 377.

A paper to be presented at the 269th meeting of the American Institute of Electrical Engineers, New York, March 8, 1912.

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(Subject to final revision for the Transactions.)

CHARACTERISTICS OF PROTECTIVE RELAYS

BY E. M. HEWLETT

The object of this paper is to describe the general characteristics of protective relays necessary for the automatic and selective action of circuit breaking and switching devices connected to electrical distributing systems. It is not my purpose to discuss or advocate any specific type or make of relay, but rather to bring before you the necessary characteristics and present a few recommendations for your consideration in selecting the proper type of relay for any particular service.

The successful operation and control of electrical distributing systems, which are becoming more complicated each year, together with the rapid increase in the application of electrical power, present engineering problems in the design of proper protective apparatus which demand and deserve the most careful attention of designing engineers. In these days when so much depends on the continuity of electrical service, our protective apparatus must be designed with this consideration in view, otherwise the service will be continually interrupted. The oil circuit breaker, the protective element of the distributing system, should be permitted to lag sufficiently so that the short circuit current of the generator will reach a value which can be economically opened by the protective apparatus; consequently a relay having selective action is necessary. On the other hand, the time limit relay should have a characteristic which will present such a rush of current as would result in the destruction of the cable and bus bar compartments. Variation in time in the operation of a circuit breaker is sufficient in some cases to determine the particular switch which will be disconnected independent of the action of the relay, consequently we should not endeavor to set the relays closer together than one-half second. Fig. 1 indicates a relay characteristic which seems to meet these conditions.

I wish to suggest the desirability of separately considering the various conditions to be met by a relay and then selecting the relay with the most suitable characteristics. We must not think that any one relay will satisfactorily comply with all operating conditions.

With the great amount of power being concentrated in such systems as the Commonwealth Edison Co. of Chicago it becomes advisable to sectionalize the buses with current limiting reactances, or even introduce external current limiting reactances in each separate generator, in order to limit the amount of short circuit current which may flow into a fault. The action of the relays will be somewhat slower, inasmuch as the current flow will be considerably less, thereby giving selective action.

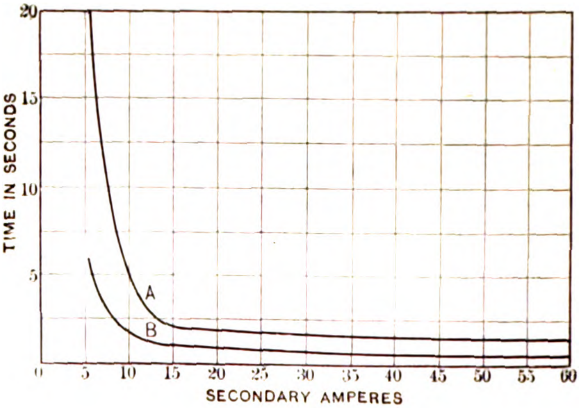


Fig. 1.

Considering first the generating station, it being of the utmost importance to keep the generators in service, as the possibility of trouble between the generators and buses is rather remote, the switches may be non-automatic or equipped with definite time limit relays having the characteristics shown in Fig. 2. This type of relay should have approximately a straight line characteristic. It should be arranged to trip the generator switch as a last resort, after the automatic switches more remote from the generators have failed to isolate the trouble. It is often desirable to have an indication of current reversal in the generator circuits without automatically tripping the generator switches. To meet these conditions a reverse current time limit relay is required which will operate on small current reversal without indicating direct overloads of short duration. The characteristics of such a relay are shown in Fig. 3

Power transformers developing internal short-circuits in a group of two or more operated in parallel, may be selectively disconnected from the circuit by an instantaneous relay sufficiently sensitive to operate on a small current reversal, in order to minimize damage.

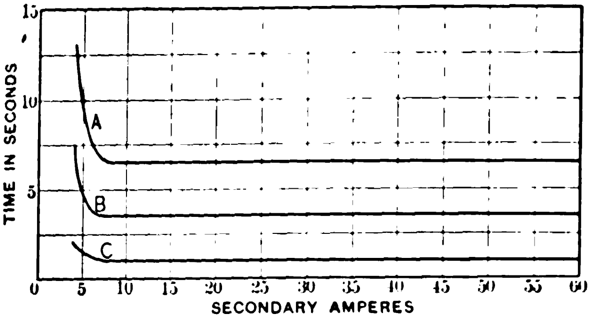


FIG. 2.

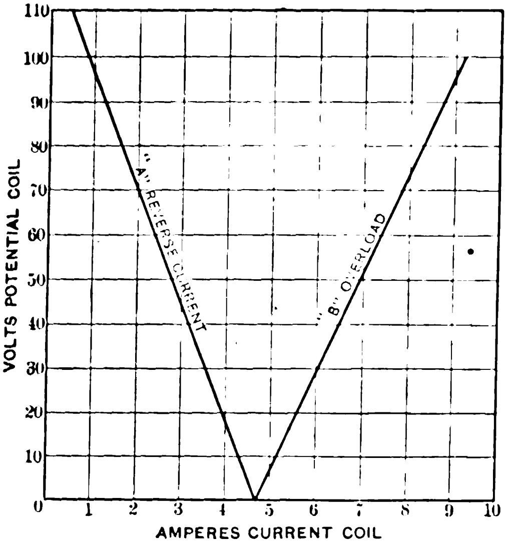


FIG. 3.

Distributing feeders from central station busses are often run several in parallel, each as a small transmission line, that is, each feeder connecting several small distributing stations in series (Diagram No. 1). This makes a set of conditions difficult to meet with a single relay as the feeders from the main bus must be cut out selectively and also the different sections in series must be selectively cut out, isolating the section and feeder in which trouble occurs. The operating characteristics of the inverse time overload relay required to meet these conditions and give satisfactory results must approximate those shown by Figs. 4, 5, and 6. It should be noted that Fig. 4 indicates the selective action which may be obtained from relays set at approx-

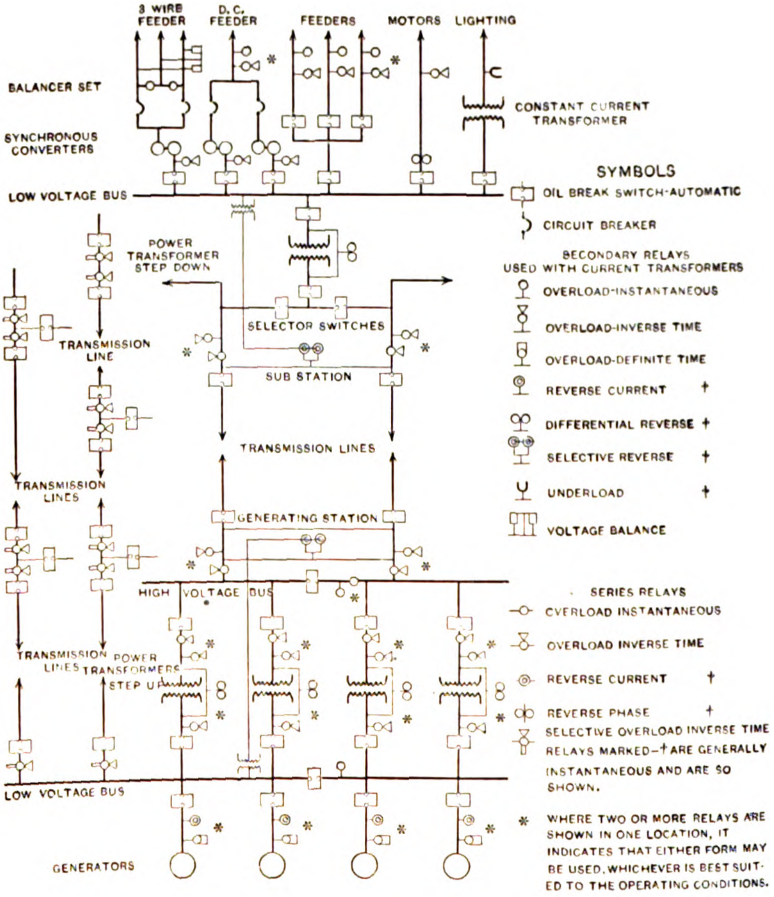


DIAGRAM No. 1

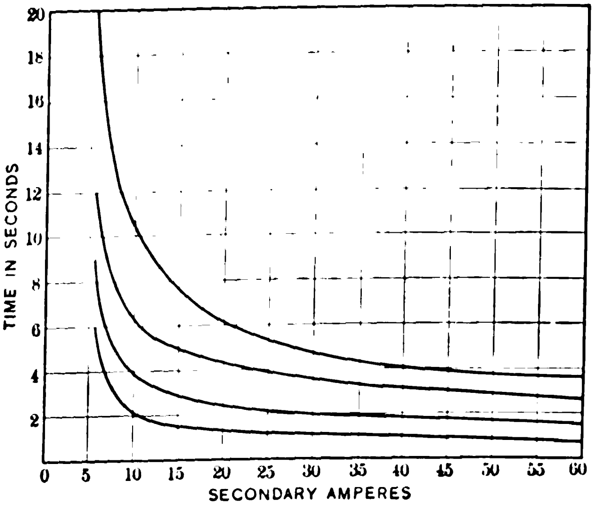


FIG. 4.—INVERSE TIME LIMIT SELECTIVE RELAY.

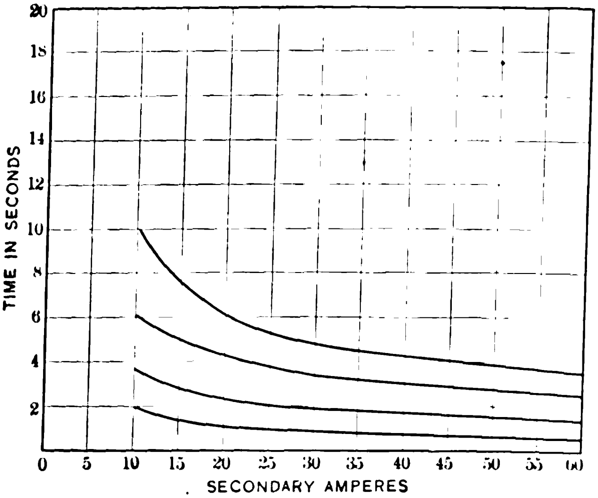


FIG. 5.—INVERSE TIME LIMIT SELECTIVE RELAY.

imately twice normal load and operated at this load. Fig. 5 shows the action of a relay set at twice normal load and operated at three times normal load. Fig. 6 shows the action of a relay set at twice normal load and operated at five times normal load. In general the conditions under which the relays are required to operate require characteristics as shown by Figs. 5 and 6, therefore the first parts of the curves, as shown by Fig 4., are of minor importance except to assist in setting the relay.

The general practice of running two transmission lines in parallel, where either of which will carry the entire load under emergency conditions, calls for a relay to automatically cut out the faulty line or section of line without interrupting service. This operating condition cannot be met by the ordinary time limit relay.

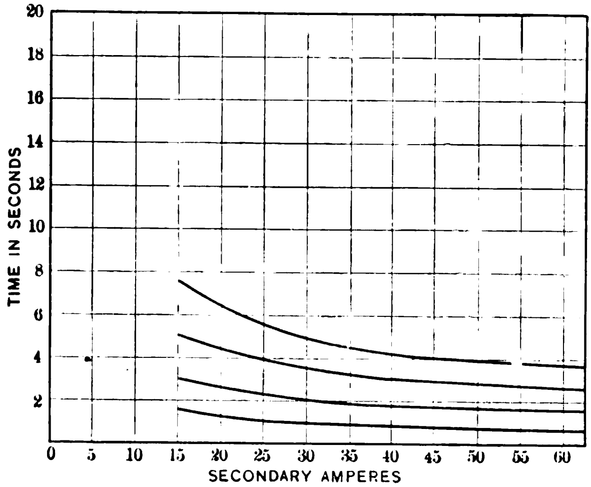


FIG. 6.—INVERSE TIME LIMIT SELECTIVE RELAY.

The relay giving curves Figs. 4, 5 and 6 will operate on unbalanced overload, but owing to the current being practically the same in each line when subject to short circuit, the time limit relays alone could not be depended on to act selectively. Consequently it is advisable to install an instantaneous differential balance relay in the incoming line of each substation in the series. This relay should be arranged to open the line in which a reversal of current occurs and at the same time lock the relay in the other line preventing its operating due to overload. The fault being instantly cut out at the incoming line end of the system, the outgoing lines from main and substation which should be equipped with inverse time limit relays will then act selectively to cut out the defective line.

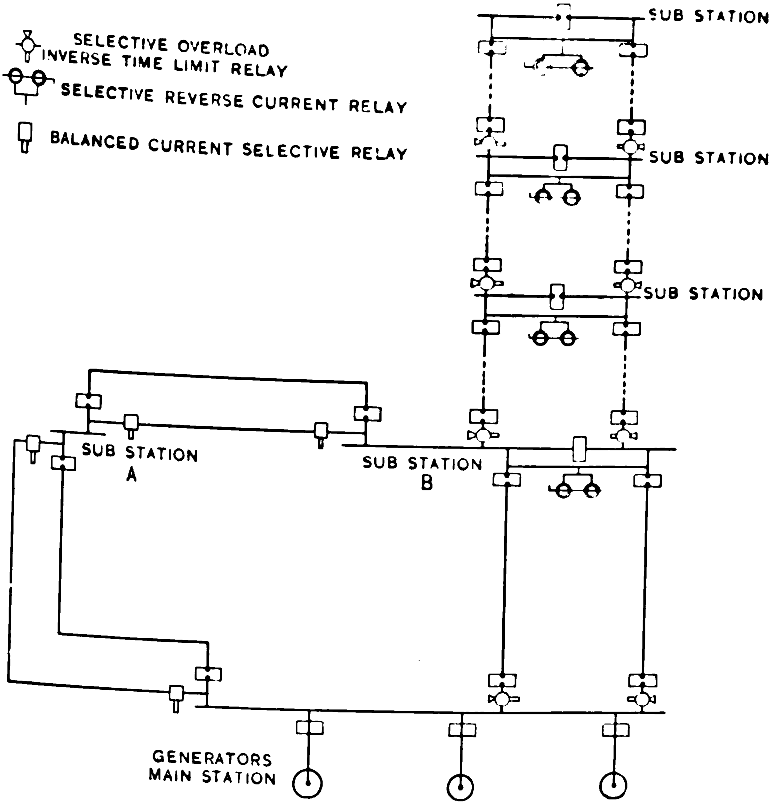

SELECTIVE OVERLOAD INVERSE TIME LIMIT RELAY
SELECTIVE REVERSE CURRENT RELAY
BALANCED CURRENT SELECTIVE RELAY
SUB STATION
SUB STATION
SUB STATION
SUB STATION A
SUB STATION B
GENERATORS MAIN STATION

DIAGRAM NO. 2.

Transmission systems are often extended to include territory not included in the original scheme for development. This often gives rise to peculiar operating conditions requiring special relay application to obtain satisfactory selective action. For instance Diagram No. 2 shows a two line transmission system to which a branch line (at the right) and a tie line from substation *A* to substation *B* were added. The single line being intended to provide as good service at *A* as at *B*, no special attention is given to the subject of selective action. The two line system should get satisfactory automatic selection by using inverse time limit relays at the outgoing line end and instantaneous balance reverse current at the incoming line end as previously described. The additional side line however, requires a relay equipment similar to the bucking transformer and pilot wire scheme much used in Europe.

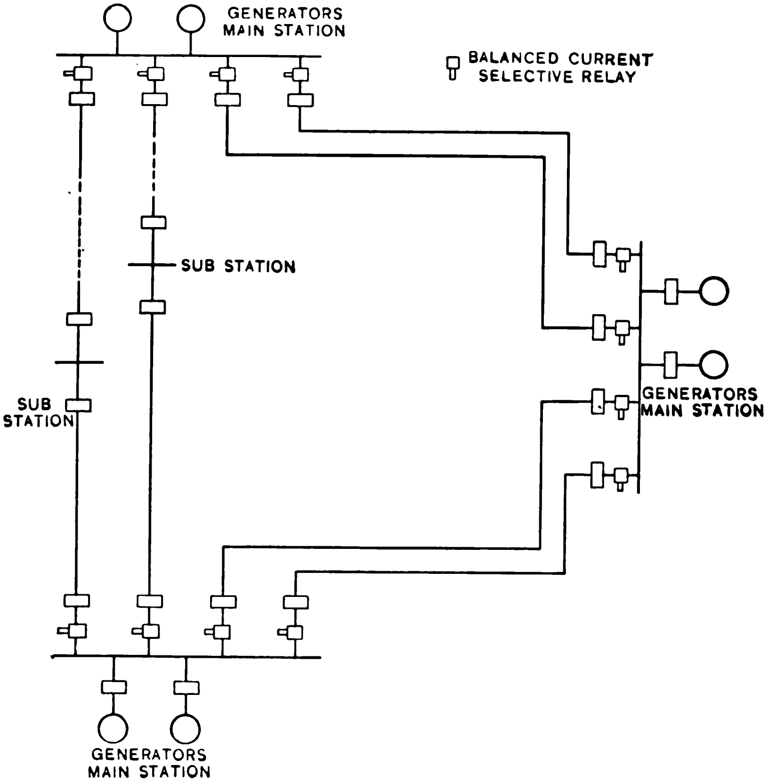


DIAGRAM No. 3.

As the current in the tie line between *A* and *B* may flow in either direction, and as in case of trouble between *A* and *B*, the *A* and *B* switches in this line should open without interruption of the two main lines or line from main station to *A*, an instantaneous relay operating on underload or current flow in both directions is required with the contacts so arranged that the switches can be closed immediately after tripping. The same equipment may be used for the line from main station to *A*. It will operate selectively on the single line, cutting out line trouble between the main station, and *A*, or *A* and *B* without interruption of service.

The addition of lines to *A*, makes it possible to run with one of the lines from main station to *B* cut out, and still have two parallel transmission lines, and to do this, it is necessary to change the incoming line balance relays at *B* to time limit relays so that each of these two lines must be protected as before, in case only one of them is in circuit, it must be protected and capable of being cut out at both ends: consequently, the balance relay must act selectively when both lines are in, and as overload when only one is used. The time feature is necessary to enable the instantaneous relays to cut out either section of the lines to *A* in case of trouble on them without interrupting service from main station to *B*.

The practice of some large central stations is to run separate feeders for each customer's load. This makes a very simple and desirable operating arrangement, the advantages of which no doubt more than offset the saving by using one feeder for several customers.

In order to keep the installation cost low, it is the practice to install an oil switch at the main or distributing station end capable of opening the line under short circuit conditions and a switch of much less rupturing capacity at the service end. The latter is arranged to open under operating overloads, but is locked for all loads above the capacity of this switch.

To obtain automatic operation for this equipment, an instantaneous or inverse time relay Figs. 4, 5, 6 set for heavy loads is required for the main station switch and a similar time limit relay set for low overloads and an instantaneous relay set for heavy loads for the service switch. The instantaneous relay renders inactive the substation time limit relay for all loads above the capacity of the substation switch, which causes the main station switch to cut out the entire feeder.

I believe that this represents the most practical way to develop service lines from central distributing stations as it allows of using lower cost substation switching equipment, and gives minimum interruption of service without the necessity of relay refinement required by some of the methods of development previously described.

The protection of apparatus such as induction motors which would be injured by sudden return of power, after failure, requires underload or low-voltage relays which will instantly disconnect the machine as soon as load current or voltage drops below say 50 per cent of normal.

Another class, along the line of elevator service, makes advisable a relay which will operate instantly on a mechanical reversal of phase at comparatively low current value.

The problems here presented are general and cover practically all of the operating characteristics required of relays commonly found for automatic protection of power systems. They are, however, actual, and I have attempted to bring them out in detail sufficiently to impress you with the importance of giving most careful engineering consideration to systems now installed, and to new developments and extensions, with reference to automatic protection, selective action, continuity of service and the consequent relay equipment involved.

DISCUSSION ON "CENTRAL STATION GENERATION OF POWER AT MINING CENTERS" (HUNTER) FT. WAYNE, IND., FEBRUARY 2, 1911. (SEE PROCEEDINGS FOR DECEMBER, 1911.)

(Subject to final revision for the Transactions.)

J. Franklin Stevens (by letter): The question of "Central Station Generation of Power at Mining Centers" as presented by Mr. Hunter deserves more than passing comment. It treats of a matter of great economic interest which has long been neglected and, possibly, the reason therefor is that it presents no novel or difficult problems in an engineering sense. There are, however, other questions involved which possess great interest to engineers and capitalists.

Mr. Hunter has discussed the question from the point of view of one particular locality, namely the central Indiana coal fields, and his conclusions are correct for that field although I disagree with him in some few minor details. Applying the same form of analysis to other fields we reach the same general conclusions with, in some cases, far more favorable results. If, for example, this same question be considered in its application to the anthracite coal fields of eastern Pennsylvania, additional reasons will be found for advocating the location of power generating stations at the mine mouth.

It is obvious that it is cheaper to transmit electrical energy than to transmit the coal from which it is generated, and the only reason why it has not been previously exploited in this locality is because the mine owners have encouraged the sale of steam coal and discouraged the sale of culm on account of the supposedly greater profit in the former than in the latter. Now, however, they are commencing to realize that a greater profit may be made by transforming the former waste, contained in culm banks, into electrical power and selling the culm in this form than can be obtained from the sale of steam coal. This is evidenced by the fact that already one mining corporation has installed such a power plant and is so encouraged by the results that it is considering further extensions of its generating station and transmission lines. Very recently one coal mining company has announced that it will establish such a plant with a capacity of 30,000 kw. some 80 miles (128.8 km.) from Philadelphia to serve a territory of 40 miles (64.4 km.) radius with prospective extension to Philadelphia.

Mr. Hunter describes conditions in the bituminous coal fields where there are practically no mine waste and no culm banks therefore the fuel possesses equal efficiency whether used at the mine or at the center of distribution and the saving is entirely in the freight, less the cost of electrical transmission, assuming the cost of coal to be the same at either point. In the anthracite fields there are vast piles of culm, which possess so much lower efficiency than steam coal that it is not considered economical to transport it, but this culm sells at the mine mouth at prices very much lower than steam coal, therefore a very material saving may be effected in the cost of fuel and this saving can be added to the saving in freight.

Considering the table submitted by Mr. Hunter, showing the saving in cost of fuel in plants of various capacities when located at the mine as compared with similar plants located at the center of distribution. I take no exception to the basis of coal consumption per kw-hr., for an average of 4 lb. (1.81 kg.) of Indiana bituminous coal per kw-hr. represents good practice, and I am prepared to accept his figures for cost of construction and maintenance of transmission lines as appropriate to the field he is discussing, but I do object to his station ratings as misleading. He assumes his plant to operate 24 hours per day with 100 per cent load, a condition never found in practice, therefore the coal consumption assumed for the different sizes of plants is in excess of the amount which would be used and, in consequence, the amount of coal used per year would be less than shown by him and the saving due to freight charges correspondingly smaller.

Employing data from plants in successful operation in Eastern Pennsylvania it will be found that 3 lb. (1.36 kg.) of No. 2 buckwheat or rice coal are required per kw-hr. while 4 lb. (1.81 kg.) of culm will be required. Rice coal costs in Philadelphia $0.85 per ton (1016 kg.) plus $1.25 per ton (1016 kg.) freight, this gives a total cost of $2.10 per ton (1016 kg.) while culm may be bought at the mine at a price not exceeding $0.25 per ton (1016 kg.). Since it requires one-third more culm than rice coal per kw-hr. the equivalent price of culm becomes $0.333 per ton (1016 kg.) showing a saving of $1.766 per ton (1016 kg.) which we will assume, for the sake of round figures, to be $1.75.

Assuming further that a plant will operate at 75 per cent of capacity for 14 hours and at 50 per cent of capacity for the remaining 10 hours of each working day and at a general average of 33 per cent for the whole 24 hours of Sundays and legal holidays we have a total output of 26,150,000 kw-hr. per year for a plant of 5,000 kw. capacity. At 3 lb. (1.36 kg.) of coal per kw-hr. we have a total annual consumption of coal in long tons (1016 kg.) of 35,000 and as we have shown a saving of $1.75 per ton (1016 kg.) by the use of culm there will be a saving of $61,250.00 per annum on coal and freight. If we now assume Mr. Hunter's figures for cost of transmission for 5,000 kw., namely $64,455.00, it shows a loss of $3,205.00 per year for a 5,000 kw. plant, against his figured loss of $13,875.00. In a 10,000 kw. plant the saving on coal and freight would amount to $122,500.00 with transmission costs of $96,012.00 giving a net saving of $26,488.00. In a 20,000 kw. plant the coal saving would be $245,000.00 with a net saving of $85,874.00. In a 40,000 kw. plant the coal saving would be $490,000.00 with a net saving of $204,646.00. In a 60,000 kw. plant the coal saving would be $735,000.00 with a net saving of $293,520.00. In an

80,000 kw. plant the coal saving would be $980,000.00 with a net saving of $412,292.00.

Large as these figures are I feel sure they fall short of the actual amount for, following local practice, some savings could be effected in the cost of installation and maintenance of the transmission lines. The substitution of wood poles in place of steel towers would lower the cost as would the plan of leasing pole rights through farm lands in place of buying a right of way. Further than this, while the cost of the plant would be the same at the mine as in a city and the overhead charges about the same, the cost of land would be much less in a mining district than in or near a large city.

The savings effected are much in excess of those shown by Mr. Hunter, even after reducing the kw-hr. output per kw. of plant capacity, and this is due to the local conditions which are far more favorable for such a project in Eastern Pennsylvania than in Indiana.

Even under conditions less favorable for saving than those shown by Mr. Hunter the Northern Colorado Power Co. decided to establish its plant at the mine and is now successfully and profitably transmitting power over a territory of 50 miles (80.5 km.) radius employing lignite as fuel.

The absence of large and reliable water powers in Eastern Pennsylvania together with the high cost of hydraulic installations will enable the mine located station, burning culm for fuel, to show a saving in operating costs as well as an increase in reliability of service.

The great saving in the cost of power production by burning culm at the mine mouth in connection with the vast quantities of culm available, the short transmissions required to reach large centers of population together with the large population to be served and the absence of any engineering difficulties will surely result in the establishment of such power plants in Eastern Pennsylvania in the near future.

J. V. Hunter (by letter): In my original paper upon the subject of "Central Station Generation of Power at Mining Centers," I based all the figures given in the table used in that connection upon the basis that the full all-day load upon the transmission line should be 100 per cent. I made the table up to meet these conditions for several reasons: One was that the time at my disposal did not permit the compilation of more data; and secondly because when the first table was made up, it seemed from a short study of it that it would be impractical to consider less than full loads from this standpoint; and lastly, under any circumstances that might lead to the adoption of such a system as a means of power transmission, one question which would be worth considering would be the placing of such a power station at the mine to carry an average all-day load of 100 per cent, while a peak load station could be built at the point of consumption to take care of these same peaks of load and avoid the heavy expense necessary for the installation of a transmission line of sufficient capacity to take care of the heaviest loads falling on the station.

As Mr. Stevens has pointed out in his discussion of the article, it might be quite possible to reduce the cost of construction of such a line by leasing the right-of-way, or by erecting a cheaper type of pole construction, though at the same time a wooden pole construction will carry a larger percentage of depreciation charges which would pretty well balance up for any saving in the original cost. The transformer capacity could to a certain extent take care of big loads, because any well constructed transformer will carry for limited periods from 25 per cent to 50 per cent overload. If the power station has been properly designed for a certain all-day load, the peaks and low spots might come near enough to balancing to produce a better condition than that which he mentions.

One item of the figures given by Mr. Stevens deserves more than passing comment, because he takes the concrete example where the freight rate amounts to $1.25 per ton and then for his fixed charges on his working line he has compared this with the charges which I computed for a transmission line 100 miles (161 km.) in length. Under such circumstances the rate of coal freight transportation charges would amount to $0.125 per ton mile, more than double the freight charges which I used in computing the original table, since under the conditions mentioned in my paper an allowance of $.006 per ton mile was made. Such conditions as Mr. Stevens mentions constitute a vitally altered case. Either he has used freight charges for transportation haul much in excess of 100 miles (161 km.) and applied them in comparison with the fixed charges on a transmission line of 100 miles (161 km.) in length, or else he is dealing with a case wherein the freight charges are much above the normal rate as found throughout the rest of America. Should the freight haulage distances in the circumstances he mentions exceed 100 miles (161 km.), the fixed charges on the transmission line would have to be recalculated. A longer distance for fuel transportation in comparison with a power transmission line has this advantage in favor of the power transmission line—that the high cost of transformer installation at each end of the line will not increase in direct proportion to the length of the distance and that therefore the only fixed charges which show relative increases are the pole line construction, conductor and right-of-way charges; yet in this connection it must be considered that since the terminal charges on rail transportation also make up a large proportion of the total cost, that for longer distances these costs should also fail to increase proportionately to the length of the haul.

However, in view of the fact that Mr. Stevens has called attention to the rate of loading on the transmission line and the fact that this would probably under no circumstances equal

100 per cent load, to show the effect of different loads on the cost of operation, Table No. 1 has been prepared. In this table the first four columns are condensed data taken from the table appearing in the original paper. Columns 5 and 6 show a comparison of freight charges with fixed charges for a load of 80 per cent of the total transmission line rating. In this column 5 gives the freight charges on the coal necessary to maintain this load. Column 6 shows the saving or loss incident to such a method. In Mr. Stevens' paper, he mentions an average load of 75 per cent for 14 hours and 50 per cent for the remaining 10 hours of each working day. This averages up a total load of 64.6 per cent. Columns 7 and 8 are figured on this basis, and it will be noted that Column 8 shows in each case a loss due to transmission.

TABLE NO. 1

COMPARISON OF COSTS OF TRANSMISSION LINE OPERATION AND OF FREIGHT CHARGES ON FUEL FOR EQUAL POWER, AT VARYING ALL-DAY LOADS ON POWER STATION

POWER STATION AT MINES; DISTANCE 100 MILES FROM POINT OF CONSUMPTION.

Freight—$.006 per ton mile.
Coal—4.0 lbs. per kw-hr.

1	2	3	4	5	6	7	8
Central Station Capacity Kilo-watts	Freight Trans. Charges for 100% Power House Load	Total of Fixed Charges	Saving by Trans. of Power	Freight Trans. Charges for 80% Power House Load	Saving by Trans. of Power	Freight Trans Charges for 64.6% Power House Load	Loss by Trans. of Power
5,000	$50,580	$64,455	$13,875 (Loss)	$40,464	$23,991 (Loss)	$32,674	$31,781
10,000	101,160	96,012	5,148	80,928	15,084 (Loss)	65,348	30,628
20,000	202,320	159,126	43,194	161,856	2,730	130,696	28,430
40,000	404,640	285,354	119,286	323,712	38,358	261,392	23,962
60,000	606,960	441,480	165,480	485,568	44,088	392,088	49,392
80,000	809,280	567,708	241,427	647,424	79,716	522,784	44,924

Attention is also called to the fact that in the figures of Table No. 1, the freight rate of $.006 per ton mile has again been used and also a coal consumption of 4 pounds (1.81 kg.) per kw-hr. After further consideration of the matter of the coal consumption in a large, high efficiency power plant of the most modern construction, it was thought possible that a consumption of 4 pounds (1.81 kg.) per kw-hr. of output may be excessive figure since some of the newer stations have claimed an average efficiency in this line of 3 pounds (1.36 kg.) per kw-hr. and some even much better than this. This, of course, would occasion a vital difference in the amount of coal consumed, reducing it 25 per cent and correspondingly reducing the freight transportation charges.

To properly consider such a condition of affairs, Table No. 2 has been arranged on the same basis as the preceding tables, but with the understanding that the coal consumption is rated at 3 pounds (1.36 kg.) per kw-hr. with a freight rate of $.006 per ton mile. It will be noted from this table that Column 1, 2, 3 and 4 again refer to 100 per cent load factor and that the items for 5000-kw. and 10,000-kw. capacity show a distinctive loss and even with a station carrying as high as 80,000 kw. the gain under such an arrangement is not a noticeable one when you consider the investment involved. Columns 5 and 6 again refer to a load factor of 80 per cent and Column 6 shows in every instance a loss in the transmission of power. Columns 7 and 8 again refer to load factor of 64.6 per cent with Column 8 showing in each case a very noticeable loss.

TABLE NO. 2

COMPARISON OF COSTS OF TRANSMISSION LINE OPERATION AND OF FREIGHT CHARGES ON FUEL FOR EQUAL POWER, AT VARYING ALL-DAY LOADS WITH COAL CONSUMPTION OF 3.0 LBS. PER KW-HR.

1	2	3	4	5	6	7	8
Central Station Capacity Kilo-Watts	Fixed Charges On Trans. Line	Freight Trans. Charges for 100% Load	Saving By Trans. Of Power	Freight Trans. Charges for 80% Load	Loss By Trans. Of Power	Freight Trans. Charges for 64.6% Load	Loss By Trans. Of Power
5,000	$64,455	$37,935	$26,520 (Loss)	$30,348	$34,107	$24,504	$39,951
10,000	96,012	75,870	20,142 (Loss)	60,696	35,316	49,008	47,004
20,000	159,126	151,740	7,386	121,392	37,734	98,016	61,110
40,000	285,354	303,480	18,026	243,784	41,570	196,032	89,322
60,000	441,480	455,320	13,840	365,176	76,304	294,048	147,432
80,000	567,708	606,960	39,252	487,568	80,140	392,064	175,644

Under the number of conditions which have now been mentioned, it becomes apparent that no hard and fast rule can be laid down to the effect that a saving may always be obtained by the transmission of power. There are too many factors entering into such an arrangement to permit any decision being given based on conclusions drawn from a single set of figures and in each case where such a power station arrangement is to be considered, all the factors entering into the matter must be carefully considerd with reference to the comparative costs of operating any single given transmission line or of paying freight charges on the coal necessary to produce power of equal capacity with the line.

REPORT ON THE PANAMA CONVENTION OF 1912

The members of the Panama Canal Trip, leaving on the United Fruit Company's steamship " Almirante " from New York, assembled on board shortly before noon on January 17, 1912, and were speeded on their journey by many regretful friends. Leaving the pier about one p.m., the ship made its way down the bay to the open ocean amid ice floes, slowly leaving behind the freezing weather of New York City.

The sea was smooth and everyone, for the first and last time, reported for lunch. Sad to relate, some of our party began to fall by the wayside and at dinner vacant places were noticed about the dining tables.

On Wednesday afternoon, the revised printed itinerary and the official badges were distributed, thus enabling the members to quickly identify and become acquainted with one another. All the officers were decorated with badges on the evening of the 17th and honored us by wearing them throughout the trip. The writer made a special effort to introduce everyone so that all should become acquainted at the earliest opportunity and thus assist in making the party homogeneous. The writer requested Mr. H. J. Douds to serve on the general committee with Prof. Wurts and himself in charge of the Panama Convention. As none of the members of this committee was familiar with the details of the trip further than was shown in the printed documents and the correspondence in hand, it became necessary to hold numerous meetings on the voyage down in order to settle the principles to guide us during our stay on the Isthmus, as well as to arrange for the financial requirements necessitated by the Jamaica trip and the special train service in the Canal Zone. A finance committee, consisting of Mr. Greenidge, chairman, Mr. Leeds and Mr. Lawton, was appointed and in conference with this committee the general committee established the unit prices for the various trips in which the members were about to participate. Throughout the trips, the finance committee served in numerous capacities besides that of mere finance, for each man on the committee could quickly communicate any information to those who had been assigned to him in a fiscal capacity. On combining with the " Cartago " party, Mr. Gerry, Mr. J. C. Smith and Mr. Schuchardt were added to this committee to arrange with the members on their boat in regard to financial matters.

The writer appointed a publicity committee, consisting of Mr. W. K. Dunlap chairman, Mr. Edmonston, and Mr. Reist, to gather and record news of the trip. Their duties also included keeping every member of the party fully informed of events aboard the ship. Their work was successful in the latter respect and they are now collating the information which they have received in order to put it in permanent form for publication. On the Isthmus, Messrs. Barnum, Schuchardt and

Pocock besides Mrs. Whitmore, Mrs. Smith, Mrs. Freeman and Mrs. Claflin were added to this committee. An athletic committee consisting of Mr. Rose, Mr. Lawton and Mr. Palmer was appointed to organize and conduct athletic sports on the deck, and a music committee, consisting of Messrs. Bates and Lawton, with the cordial coöperation of Dr. Hadley, was appointed to gather musical talent for the entertainment of the party. Realizing the importance of having trained men to make note of the occasions for thanks for the various courtesies extended to our party, the writer appointed Mr. Hering chairman, Mr. Freeman and Mr. Schuchardt a committee on resolutions and the members of this committee have performed their duties successfully and with credit to the Institute.

On account of the valuable information which would be collected by the members using cameras, a photographic committee was appointed consisting of Messrs. Reist chairman, Leeds, Barnum and Pocock, whose duties were to collect all available pictures of merit and interest for a permanent Institute record. About forty cameras of different sizes were in the hands of the members and nearly four thousand pictures were secured. From this the committee will select a suitable number to appropriately represent the essential and lasting impressions of the trip.

The party was scheduled to stop at Jamaica on the way to Colon and Panama, and on the trip down, the members entertained and occupied themselves with shuffle board, ring toss, walking, cards and other amusements. Betting on the day's run was an amusing and to some a profitable incident each day.

Dr. Hadley, the ship's surgeon, entertained us by his musical talent at the piano on Thursday evening, and on Saturday afternoon, January 20, an enthusiastic and well attended athletic meet was held. A tug-of-war was hotly contested while a pillow fight on a spar and a duck fight added much to our entertainment. The walking match for the ladies was won by Mrs. Dunlap, while the mile walk for the men was won by Mr. Grant. The potato races were well and closely contested. The prizes were distributed to the winners by Dr. Humphreys with appropriate encomiums of praise. On Sunday, at 11, divine services were conducted in the music room by Dr. Humphreys assisted by Dr. Hadley, Mr. Lawton and Mr. Bates. The brilliant evenings were employed in studying the starry heavens.

The general committee had had printed on board a circular showing the cost of the Jamaica trip and the special train service on the Canal Zone and these were distributed so that the members would understand the reason for the visits of the finance committee. Also tickets covering the three parts of the Jamaica trip were printed on board and proved of great convenience to the members. Sunday afternoon Cuba was sighted and we passed its eastern end at sunset. Changing our course, we headed for Port Antonio on the northern coast of Jamaica, where we arrived early Monday morning. Everyone was up early to see the glorious beauties of the shores and mountains. To many of us Jamaica afforded the first impressions of tropical vegetation and the beautifully clear morning permitted us to view the landscape at its best. Having had breakfast, we assembled on deck and watched the progress of our ship in entering the harbor and coming to anchor. After the usual port formalities, we embarked in launches and row boats for the wharf and proceeded to the Hotel Titchfield. At nine o'clock we entered carriages for our ride to Blue Hole, about six miles east of Port Antonio and on the north shore of the island. A most beautiful and interesting drive was taken along the shore line with a few digressions inland and all over a fine road lined with luxurious tropical vegetation such as cocoanut, banana, mango and bamboo trees. Brilliant flowers lined the road and covered the fields. On arrival at Blue Hole we found a circular sheet of water, fed from the ocean through a small inlet, quite clear and wonderfully blue in tint. Some members of the party voyaged around on the surface and incidentally were caught in a slight and sudden downpour of rain, while others ate cocoanuts brought down by the natives from the trees and opened with their machetes, and drank the milk from the opened shells. Bananas were eaten and kola was drunk, photographs taken and then we returned to the Hotel Titchfield, where a delightful lunch was served, a special menu being printed in our honor. Every courtesy was shown to our party by the United Fruit Company's representatives.

After luncheon we were taken in carriages to the railroad station where our special train on the Jamaica Government Railway awaited us and started at 1:30 p.m. for Kingston. In the meantime our steamer had left Port Antonio for Kingston, where it was due to arrive at about three in the afternoon. The trip across Jamaica took about four and a half hours, and was a revelation in the way of showing, to many of us for the first time, the features of a tropical country and also the character and habits of the natives in the country districts where cocoanuts and bananas are grown. The railway passes through 38 tunnels on its way to Kingston, the mountain ranges being high and compelling the railway to seek a passage through, rather than over them. At Annatto Bay Messrs. Leeds, Stokes, and Schoonmaker left us in order to drive over the roads to Kingston. They arrived safely aboard ship at half past ten that evening. Our train arrived at Kingston at six o'clock, after the most interesting day in our party's itinerary. Some went directly to the steamer, while others went to the Myrte Bank Hotel for dinner. Captain Henshaw joined a party at dinner at the hotel and the evening was spent in discussing the charming features of the day.

On Tuesday, many indulged in shopping in order to be properly prepared for the tropical climate which we expected to meet on the Canal Zone and on board ship. Some visited the markets, the barracks, the stores and other points of interest in Kingston. Lunch was had on board and we sailed at two p.m. for Colon, after a most interesting stay in the newly rebuilt city of Kingston. The inner harbor is well protected by the land on which Port Royal is situated, and the barren mountain range rises abruptly from the shores of this inner bay. The landscape is not as interesting as on the north side of the island for the rains borne by the trade winds do not reach the south side in such plentitude as on the north side.

Shortly after reaching the open Caribbean Sea, a heavy swell was encountered, causing some of us to seek the quiet of our staterooms, and this quartering sea remained with us until we arrived inside the harbor of Colon on Thursday noon, January 25th. Land was sighted on Thursday morning and shortly thereafter we began to pick up recognizable points in and about Colon. Toro Point and lighthouse were easily discernable objects in the distance. Everyone was on deck, eager to go ashore and proceed to Panama City and Ancon.

On January 24th, the following aerogram was received from Mr. C. E. Waddell, the Institute representative on the S.S. "Cartago" which left New Orleans on Saturday, January 20th:

> New Orleans party sends greetings and anticipate our meeting with pleasure.

and the following reply was sent:

> C. E. Waddell,
> S.S. Cartago.
> New York delegation appreciate greetings and reciprocate expressed pleasure of meeting at Colon. Let me know exact number in your party.
> George F. Sever.

This reply was received on board the "Almirante":

> To Geo. F. Sever,
> Chairman A.I.E.E.,
> S.S. Almirante.
> Forty-seven in party, probably arrive about two o'clock.
> Waddell.

The S.S. "Almirante" docked at 12 noon, and we were met and greeted by Mr. E. Schildhauer, Mr. Kratz, Col. Sibert, Mr. Cornish and others who informed us of the arrangements which had been made for our comfortable transportation across the Isthmus of Panama to the Hotel Tivoli, which was to be our official headquarters during our stay in the Canal Zone. The Health Officer passed all members of the party without question and no customs inspection was necessary as all our luggage was at once placed on a baggage car and later attached to our special train which took us to Panama City. We lunched on board, Mr. Schildhauer, Mr. Kratz and Mr. Cornish joining us, and at 2 p.m. the "Cartago" docked, Captain Lamb bringing the New Orleans party safely to port. After mutual greetings, we boarded our special train and proceeded at 3.45 p.m. to cross the Isthmus on the Panama Railroad to Panama. Some glimpses of the Canal were seen en route and we arrived at Panama at 6.30, proceeding by carriage directly to the Hotel Tivoli. There we found that all arrangements had been made for our comfortable housing, and after having found our quarters, we enjoyed our first dinner on the Canal Zone. The members of the two ships' parties began to meet and to introduce each other, so that after a brief period the two sections became as one and thereafter moved as one on our inspection trips over the Zone.

New Orleans Party on "Cartago"

Representing thirteen States, the District of Columbia, Canada, Hawaii, and Jamaica, the New Orleans party met as a body for the first time on the United Fruit Co's. steamer "Cartago" at St. Joseph St. wharf, January 20, 1912. The party numbered 52 in all and was composed of 16 Institute members, 10 ladies, and 26 guests; included in the latter were a number of members of our fellow Societies, the Civil, Mechanical, and Mining Engineers. Delayed slightly in loading, the "Cartago" did not sail until late in the afternoon, and as a consequence the sight of the Mississippi delta and jetties was missed. Favored with beautiful weather throughout the trip, the voyage was without unpleasant incident although the steady swell of the Caribbean created a third grade of membership—associate, full and empty members.

On the afternoon of January 23d, the wireless operator reported that he had picked up the "Almirante" which was about 400 miles distant and then in the vicinity of Jamaica. On behalf of the party, Mr. Waddell wired Professor Sever: " New Orleans party send greetings and anticipate our meeting with pleasure." On the following day, cordial greetings were returned by our New York friends.

On the evening of the 24th Captain Lamb gave a dance for the Institute members. Artistic and attractive programs bearing the insignia of the Institute were prepared by the ship's printer, the deck was arranged for dancing, refreshments were served in the intermission, and a most delightful evening spent.

On the following afternoon land was sighted. The approach to Colon presented a never to be forgotten scene. The "Almirante" reached port ahead of the "Cartago." Soon after lunch the more powerful glasses revealed the outlines of the shipping in the harbor. As the harbor was approached the blue of the Caribbean was displaced by a greenish tint. Colon lies low and squatty on the water front; the blue mountains contrast sharply and pleasingly with the green of the luxurious tropical foliage; conspicuous and beautiful above all other objects is the magnificent grove of palms planted by the French along the broad avenue leading to their executive building, and flanking the statue of Columbus, also erected by them. The special train awaited our arrival, the baggage was quickly transferred, the members of the reception committee were met for the first time, and the identity of the New Orleans party was merged into the body of the Institute as a whole.

On Thursday evening, the general committee and the finance committee met in order to establish for the whole party the principles which were to govern us during our stay on the Isthmus. The following resolution was formally passed in order to protect our hosts and the members of the party from embarrassment on our trips on the Zone in our special trains and other means of travel:

RESOLVED, that the special transportation facilties placed at our disposal through the courtesy of the Isthmian Canal Commission, as represented by the Chairman, Colonel G. W. Goethals, be reserved to immediate members and guests wearing the A.I.E.E. official badge and further to those friends of any Member or Associate of the A.I.E.E. who can be vouched for as when introducing such friends to the hospitalities of a club.

The sense and letter of this resolution were rigidly adhered to throughout our stay and prevented access to our trains of unauthorized persons who were anxious to view the work of the canal by means of the same extraordinary facilities which enabled us to examine the details so closely. Copies of the official handbook of the Panama Canal had been distributed on the train from Colon so that we had important and accurate data regarding the monumental engineering work which we were about to visit. An interesting and active itinerary had been planned for us, which was closely followed.

The first trip was started on our special train leaving Panama at 8 a.m. on Friday and was over the railroad to the famous Culebra Cut. The following engineers of the Commission accompanied us on the train and explained the details of the work in progress: Col. Gaillard, in charge, Mr. Rousseau, Mr. Robinson, Mr. Zinn, Mr. Kratz, Mr. Bronk, Mr. Martell, Mr. Goldmark, Mr. Cornish, Dr. Dietrow, Mr. Sessions, Mr. Schildhauer.

The marvellous work of the steam shovels, the churn and compressed air drills, the dynamite squads and the dirt trains was seen here at its best, and startled the mind into an appreciation of the magnitude of the operations which all the engineers working as a unit were successfully conducting. Coöperation was the keynote of the work and our first appreciation of this thought was many times accentuated by the later visits in our itinerary. Col. Gaillard and others explained to us the slides which take place in both the dry and rainy seasons, and clearly indicated the steps which were being taken to obviate these in the future. It was easy to see in places the actual movement of the dry earth over the underlying rock foundation, and in some places the earth for many feet back from the cut was in slow motion in the direction of the excavated cross-section of the cut. The rising of the floor of the canal was noticed in some places where the pressure of the earth on the sides of the cut was sufficient to establish an unbalanced pressure and cause the earth to rise. The remedy for this was to remove the earth on top of the sides of the cut to a sufficient depth to relieve that unbalanced pressure which caused the floor of the canal to be forced upward.

After passing through the cut we proceeded to the Gorgona shops where construction and repair work on much of the machinery of the Commission is performed. Locomotives, cars, cranes, etc., and much smaller apparatus are here repaired. The special train then took us to Culebra where we were shown models of the locks and dams and a comprehensive explanation of the working of the locks was given by Mr. Cornish. After lunch, served at the Commission Hotel at Empire, the party proceeded on foot to the suspension bridge over the Culebra Cut and stood fascinated by the performances of the steam shovels, work trains and drills in the cut below and also by the intermittent small blasts which were the result of the breaking up of the boulders or small masses of rock.

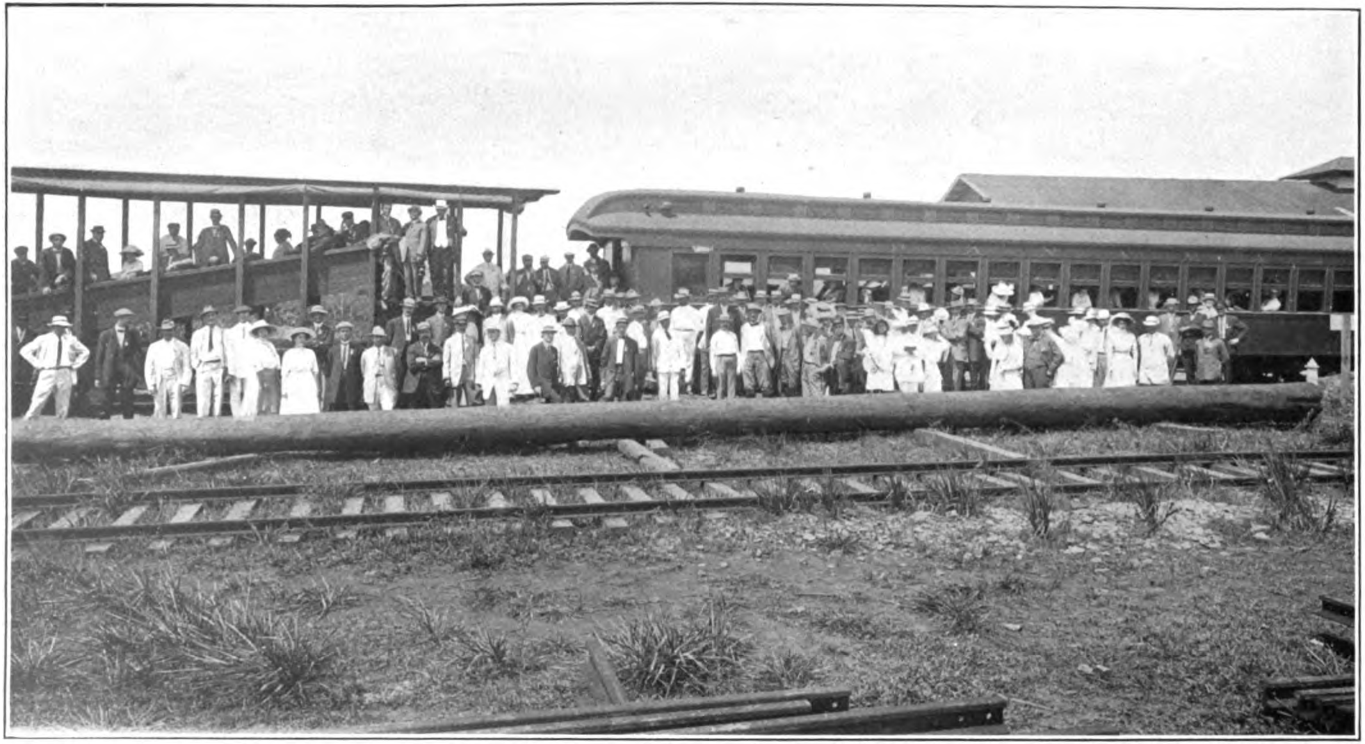
Our minds were overcome by the wonder of it all. We sought our train and returned to Panama in time to visit the Ancon Hospital under the kindly guidance of Col. Mason. There we found an extensive collection of buildings of wood protected by modern fire apparatus, designed for hospital purposes. Medical, surgical and accident wards indicated by their equipment and conduct a very complete knowledge of the most modern methods of handling the sick and injured. The operating rooms and wards were closely observed and the Nurses' Home was inspected with much appreciation for the comfort afforded to those who are caring for the sick. Separate wards for the different nationalities have to be provided. The hospital is located on the side of Ancon Hill with a beautiful outlook over the country of Panama and having the Hotel Tivoli in the foreground. Royal palms furnish decorative features to the grounds. The completeness of the hospital and its wonderful cleanliness is strong testimony to the watchfulness which is being exercised in every detail relating to the conduct of the canal work.

Friday evening had been left free for individual preference, no organized function being arranged. The general committee met in a long session

PLATE XIII
A. I. E. E.
VOL. XXXI, NO. 3

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS AT Y.M.C.A. BUILDING, GATUN

[PANAMA CONVENTION]



AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS PARTY AT GATUN

[PANAMA CONVENTION]

to arrange for the proposed reception and dance Monday evening and to consider other matters of importance to our welfare.

Saturday morning we were met at our train at Panama by Colonel Goethals, to whom all the members of our party were introduced before boarding the train. He accompanied us as far as Culebra explaining engineering matters on the way. He left us with a hearty greeting and wishes for a successful stay. We proceeded to Gatun and the Gatun locks where the party was taken in two sections on a small work train to the lower galleries of the upper locks. Then an inspection of the Gatun dam, spillway, power plant, and automatic work railway was made and later we went to Mindi to see the intersection of the old French Canal and the new American Canal entering from the Caribbean Sea. Dredges and drills were observed working in the American Canal. Previous to lunch at the Gatun Hotel, official group photographs were taken of the whole party, on the steps of the Y.M.C.A. Building.

After lunch, we visited the top of the Gatun Locks, inspecting with deepest interest the electrical devices for moving the gates, holding them closed by interlocking them, operating the inlet and outlet valves and the proposed electric locomotives for moving the vessels through the locks. A number of these devices have been the result of the work and invention of Mr. Schildhauer. Regaining our train, we proceeded over the relocated Panama Railroad to Frijoles, viewing the new bridge over the Chagres River and joined the main line on our way to Panama. A glorious day, filled with many wonderful and awe-inspiring engineering achievements, was made more valuable through the continual courteous explanations of our hosts who accompanied us, these including Col. Goethals, Mr. Goldmark, Mr. Watt, Mr. Cornish, Mr. Schildhauer, and Mr. Smith. Saturday evening was the occasion of the reception and dance given at the Hotel Tivoli to the visiting delegation of the A.I.E.E. by the Tivoli Club. This was a brilliant social function and gave many of us the opportunity of meeting our friends on the Canal Zone in a manner conducive to the most friendly spirits. Our hosts were most cordial and we are deeply appreciative of the courtesies extended to us on this charming evening.

On Sunday, the party left by special train at 9.30 a.m. for Balboa, where two tugs transported us to Taboga Island. Small row boats took the members of the party ashore, where Col. Gorgas, Col. Mason and Major Ames, who accompanied us on the excursion, showed us the Commission Sanitarium. Some of us visited the small native town while others betook themselves to the fine beach for a swim in the waters of the Pacific Ocean. The old church was inspected and also some samples of the natives' dancing. The Sanitarium is used for the recuperation of the employes after any severe illness or malarial fever—a beautiful spot and having on the sides of the hills back of the town many acres of the famous Taboga pineapples. A delicious lunch was enjoyed in the main building, the first course consisting of pieces of the local pineapple. We embarked on our tugs by means of the small boats and returned to Balboa where our special train conveyed us to Panama in time for dinner. Many took occasion to drive through Panama City after our return from Taboga and found the jail an interesting study in the way of a penal institution in a Central American State. Sunday evening had no special assignment.

An official list of the party had been printed at the Mount Hope Printery and was distributed on Sunday.

STEAMER "ALMIRANTE."

Alverson, H. B., Buffalo, N. Y.
Bates, G. M., Boston, Mass.
Barron, Mrs. J. H., Oneida, N. Y.
Barron, J. Homer, Oneida, N. Y.
Battey, P. L., Chicago, Ill.
Claflin, George E., Boston, Mass.
Claflin, Mrs. G. E., Boston, Mass.
Dalzell, W. S., Pittsburgh, Pa.
Dalzell, Mrs. W. S., Pittsburgh, Pa.
Douds, H. J., New York, N. Y.
Douds, Mrs. H. J., New York, N. Y.
Dunlap, W. K., Pittsburgh, Pa.
Dunlap, Mrs. W. K., Pittsburgh, Pa
Dunne, Hugh J., Ottawa, Ont.
Edmonston, E. D., Baltimore, Md.
Freeman, W. W., Brooklyn, N. Y.
Freeman, Mrs. W. W., Brooklyn, N. Y
Grant, W. W., New York, N. Y.
Greenidge, C. A., New York, N. Y.
Greenidge, Mrs. C. A., New York, N. Y.
Hanna, J. H., Washington, D. C.
Hanna, Mrs. J. H., Washington, D. C.
Hatzel, J. C., New York, N. Y.
Hering, Carl, Philadelphia, Pa.
Hicks, T. N., Niagara Falls, N. Y.
Humphreys, A. C., New York, N. Y.
Humphreys, Mrs. A. C., New York, N. Y.
Keller, E. E., Detroit, Mich.
Keller, Mrs. E. E., Detroit, Mich.
Lawton, A. H., New York, N. Y.
Leeds, M. E., Philadelphia, Pa.
Logan, H. B., New York, N. Y.
McClelland, R. J., New York, N. Y.
McClelland, Mrs. R. J., New York, N. Y.
Morris, Wm., Olean, N. Y.
Murphy, John, Ottawa, Ont.
Noble, James F., Oklahoma City, Okla.
Northrup, E. F., Princeton, N. J.
Page, Wilson K., Olean, N. Y.
Palmer, A. P., Brooklyn, N. Y.
Pratt, G. C., Atlanta, Ga.
Pratt, Mrs. G. C., Atlanta, Ga.
Quiren, W. A. C., Olean, N. Y.
Reist, H. G., Schenectady, N. Y.
Rogers, C. H., New York, N. Y.
Rose, G. S., Yonkers, N. Y.
Ross, Fred, Olean, N. Y.
Schoonmaker, J. M., Jr., Princeton, N. J.
Sever, George F., New York, N. Y.
Sharer, Carl W., Philadelphia, Pa.
Spalding, Henry K., New York, N. Y.
Stevens, J. Franklin, Philadelphia, Pa.
Stevens, Mrs. J. Franklin, Philadelphia, Pa.
Stokes, J. Stogdell, Philadelphia, Pa.
Veeder, C. H., Schenectady, N. Y.
Vinson, S. Glen, Mansfield, Ohio.
Wurts, A. J., Pittsburgh, Pa.
Wurts, Mrs. A. J., Pittsburgh, Pa.

STEAMER "CARTAGO."

Anderson, Mr., Sheboygan, Wis.
Barnes, Stuart, Syracuse, N. Y.
Barnum, T. E., Milwaukee, Wis.
Barnum, Mrs. T. E., Milwaukee, Wis.
Bingham, H., Syracuse, N. Y.
Brodt, C., Syracuse, N. Y.
Bumgarner, J. A., Keddie, Cal.
Bumgarner, Mrs. J. A., Keddie, Cal.
Burke, D., Lewiston, Mont.
Campbell, Wm., Detroit, Mich.
Chedsey, N. L., Denver, Colo.
Chedsey, Wm. R., Denver, Colo.
Chowins, C. E., Grand Island, Neb.
Duffy, F. E., Chicago, Ill.
Duffy, Mrs. F. E., Chicago, Ill.
Foeste, Otto, Sheboygan, Wis.
Foeste, Mrs. Otto, Sheboygan, Wis.
Foeste, Miss F., Sheboygan, Wis.
Fritts, Charles E., Kansas City, Mo.
Galloway, John R., Washington, D. C.
Gaylord, Mr., Honolulu, H. I.
Gerry, M. H., Jr., Helena, Mont.
Glenn, Charles S., Syracuse, N. Y.
Gray, F. D., Syracuse, N. Y.
Gray, Owen H., Salt Lake City, Utah.
Herbert, C. G., Syracuse, N. Y.
Hilger, David, Lewiston, Mont.
Hogle, James, A., Salt Lake City, Utah.
Hulett, F. N., Webb City, Mo.
McKeehan, D. C., Colorado Springs, Colo.
Merriman, Mansfield, New York, N. Y.
Merriman, Mrs. Mansfield, New York, N.Y.
Neill, Gen. J. S. M., Helena, Mont.
Palmer, Mr., Honolulu, H. I.
Paul, Earl W., Los Angeles, Cal.
Pocock, M. A., St. Paul, Minn.
Prescott, Mr. Washington, D. C.
Rutherford, G. S., Syracuse, N. Y.
Saunders, C. S., Montreal, Que.
Schuchardt, R. F., Chicago, Ill.
Schuchardt, Mrs. R. F., Chicago, Ill.
Sinclair, H. H., Los Angeles, Cal.
Smith, Julian C., Montreal, Que.
Smith, Mrs. Julian C., Montreal, Que.
Stratton, F. A., Mt. Vernon, N. Y.
Stratton, Mrs. F. A., Mt. Vernon, N. Y.
Turner, F. K., Helena, Mont.
Waddell, Charles E., Asheville, N. C.
Whitmore, J. D., Grand Island, Neb.
Whitmore, Mrs. J. D., Grand Island, Neb.
Whitmore, B. C., Grand Island, Neb.
Wickes, G. T., Helena, Mont.

An invitation to the reception and dance on Monday evening at the Hotel Tivoli was formally published in the two Sunday newspapers—a rather unusual method of inviting one's guests to such a social function, but the only means available for reaching our prospective guests within the time at our disposal.

> **The American Institute of Electrical Engineers requests the honor of the presence with their ladies, of the Commissioners and Officials of the Panama Railroad; the Tivoli Club and guests; the members of the University Club; and the members of the Strangers' Club at a reception and dance at the Tivoli Hotel, Monday evening from 9 to 12. A special train will leave Panama for Colon at 11.50 p m.**

On Monday morning at eight o'clock we left on our train for a wonderfully interesting visit to the Pacific Division, where we viewed in turn the Pedro Miguel locks and the Miraflores locks and dam. These are well along in their construction and evidenced the massiveness of the work. Hydraulic excavation was being conducted between the locks where the soil was of such character as to lend itself to such treatment. The use of the large concrete mixers and travelling cranes for the depositing of the concrete was best studied here, and we could also readily inspect the floor of the locks and the structures of the side walls with the seats for the Stoney gates. On this technical excursion we were accompanied by Col. Hodges, Col. Gaillard, Mr. Cole, Mr. Watt, Mr. Schildhauer, and others, who, in their full knowledge of the work, were a constant mine of information for our inquiring minds.

Returning to Panama for lunch, many took the opportunity to drive to old Panama to view the ruins of the old city destroyed by Morgan. Others went to Culebra to look over the plans and drawings relating to the canal work while parties visited the stores of Panama City. Mr. Douds and the writer made an official call upon Dr. Arosemena, President of the Republic of Panama, to invite him to our reception to be given that evening at the hotel. He greeted us most cordially and pleased us by a charming acceptance. In the evening the members of our party gave a reception and dance to the officials of the Canal Zone and the members of the Tivoli Club, the ladies in the receiving line being Mrs. Humphreys, Mrs. Schuchardt, Mrs. Douds, Mrs. Barnum, Mrs. Freeman, Mrs. Stratton, Mrs. Greenidge, Mrs. J. C. Smith, Mrs. Wurts, Miss Whitmore. Dr. Arosamena arrived at half after nine and met all the members of our party. During the supper in the Banquet Hall, the following resolutions were read by your official representative and were heartily approved by the party. Col. and Mrs. Gorgas, Gov. and Mrs. Thatcher, the American Minister and Mrs. Dodge, Dr. Perry and many others officially connected with the Canal Zone were present as our guests.

> We, the visiting delegation of the American Institute of Electrical Engineers to the Panama Canal, desire to record our sincere appreciation of the extreme courtesies enjoyed during our sojourn on the Isthmus and our profound admiration of the monumental task which is approaching successful completion.
>
> We have been greatly impressed with the immensity of the undertaking, the rapidity and thoroughness of the work performed and the assured mastery of the many difficult problems confronting the Commission and its staff.
>
> The splendid work of all the branches, conducted in healthy rivalry, has been everywhere noticeable. The hitherto unapproached sanitary provisions and hospital arrangements and the superb engineering organization and methods of work have excited our highest admiration.
>
> We are greatly indebted to Colonel Goethals and his associates for their personal

courtesies, for the most cordial and unfailing attention of the various officials in charge of the different divisions of work and we have recognized the force of their example in the noticeable desire of all the employes to assist in making our visit pleasant and instructive.

The splendidly prepared and faultlessly executed arrangements of the local committee, under the genial direction of Mr. Schildhauer, have afforded unusual opportunities for inspection at close range of all the important features of the Canal and we appreciate most fully the constant and untiring efforts in our behalf.

We have been surprised and delighted by the comfort with which so comprehensive a program of business and social events has been carried out and we shall take home a most delightful memory of tropical hospitality with entire freedom from discomfort and fatigue.

We have been especially gratified to note the important part in the Canal construction taken by members of our Institute and the effective and original work performed by them, notably by Mr. E. Schildhauer, the electrical and mechanical engineer of the Commission, in the designing of the mechanical and electrical apparatus for the operation of the locks. We tender our congratulations to them for their success and for the credit reflected by their accomplishments upon the Institute.

We foresee with confidence and with patriotic pride the early realization of the hope of the Commission in the union of the Pacific and Atlantic oceans and we rejoice that this world project is to be so soon attained by the utilization of American money, brains and enterprise.

The resolutions were published in full in the two papers issued in Panama.

On Tuesday morning, we visited the large rock crusher at Ancon Hill quarry, this being driven by a 250-h.p. induction motor. Thence we went to the breakwater being constructed from the mainland to Naos Island where preparations are being made to erect fortifications to command the entrance to the canal at the Pacific end. Many acres of land are being filled at the Pacific end to be available later for business and other purposes. We included in this morning's trip an inspection of the shops and wonderful concrete docks at Balboa.

After lunch, we proceeded again to Balboa where we embarked on tugs under the guidance of Mr. Smith, Mr. Robinson and Mr. Watt, our guides of the morning's excursion, and steamed up the Canal to view the dredging work being performed by the steam drills and old French dredges. We then steamed down to the mouth of the channel and about Naos and the other islands of that group and returned to Balboa and Panama, refreshed by our little sea trip on the Pacific.

All official organized trips were cancelled for Wednesday, individual excursions being made to those parts of the canal which demanded further study. As your official representative I made official calls at Col. Goethal's office and upon the American Minister, Mr. Dodge, Gov. Thatcher, Col. Gorgas, and Col. Mason. On Wednesday afternoon at four o'clock, President Arosemena received the members of the party at his presidential residence at a formal reception, each member being introduced and receiving a cordial greeting. Besides our party, Mr. Dodge, the American Minister, Mr. Robinson, and Mr. and Mrs. Schildhauer were present.

On Thursday morning, we left Panama at eight o'clock for Colon and embarked on the steamers "Almirante" and "Cartago" for New York and New Orleans, respectively. The former left at 2:30 and the latter at 3:30 p.m. We were speeded on our way by Mr. Schildhauer, Mr. Kratz, Mr. Smith and Mr. Cole, and in departing we left behind our sincere thanks for most extraordinary courtesies accorded to us. On our way to Kingston, the following messages were sent by wireless:

Waddell,
S. S. Cartago.
Greetings from Almirante party to Cartago party. Bon voyage.
SEVER.

Sever,
S.S. Almirante.
Reciprocate greetings and look forward to Panama party nineteen fifteen.
WADDELL.

Dr. Pablo Arosemena,
Panama.
American Institute of Electrical Engineers sends greetings to you on leaving your shores
SEVER.

Edward Schildhauer,
Culebra, Canal Zone.
Institute party sends greetings and sincere thanks for courtesies.
SEVER.

The voyage to Kingston was smooth and delightful, the moon in all its southern radiance lending wonderful charm to our progress home. Arriving at Kingston on Saturday, we stayed only a few hours there and then made our way to Port Antonio around the eastern end of Jamaica. Taking on a few passengers at Port Antonio in the early evening, we set forth for New York on a smooth and unruffled sea, which remained tranquil throughout the remainder of the voyage. Some of our party remained at Jamaica to motor and drive over the hills and valleys of this charming island.

On the evening of February 5th, a bridge tournament was held, the winner being Mr. J. F. Stevens, while booby prizes were given to a number of others.

On Monday evening a vaudeville performance was given in the smoke-room. Impromptu contributions in the form of singing, story-telling, dancing and acting were made by the members of the party.

The New York boat reached its dock at 2 p.m. on February 8, 1912.

NEW ORLEANS PARTY ON "CARTAGO"

Thursday, February 1st, leave was taken from our Isthmian friends, and the two parties again separated. The "Almirante" sailed about an hour in advance of the "Cartago," and as she slowly drifted out of the slip the bugler from the "Cartago" played "Auld Lang Syne" and farewells were waved.

The return was without incident. Rough and inclement weather was experienced on reaching the Gulf, but the boat arrived about on schedule time.

The account of the party would be incomplete without allusion to the excellence of the ship and the courtesy of the officers. Extremely solicitous for the comfort and pleasure of their passengers, the officers headed by Captain Lamb did all in their power to make the voyage agreeable, and they were successful.

It has been suggested that the Institute go to San Francisco via the Canal in 1915; the members of the New Orleans party heartily concur in this plan, and hope to meet again on that occasion.

The trip was most successful in every particular, the only unfortunate occurrence being the accident to our honored guest, Dr. A. C. Humphreys, who sprained a tendon in his leg while inspecting the Gatun Locks on

January 27th. He was confined to his room the balance of his stay on the tour and during the voyage north.

On Wednesday evening, preceding the entertainment, the following resolution, prepared by the committee on resolutions, were presented by Mr. Hering to those addressed.

PANAMA CONVENTION
OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

RESOLUTIONS

The Members of the American Institute of Electrical Engineers and their guests, who have taken part in the eminently successful, very instructive, and most enjoyable trip to the Panama Canal, feel grateful to Mr. S. D. Sprong and his Committee for having suggested and organized the trip.

CARL HERING, GEORGE F. SEVER,
Chairman Official Representative.
Committee on Resolutions
February 6, 1912.

The members and guests of the Panama Convention of the American Institute of Electrical Engineers on the S.S. Almirante, take pleasure in expressing to the United Fruit Company, and in particular to its representative Mr. H. A. Ingwersen, their appreciation of the courtesies extended to them in connection with their trip by sea, to and from Colon.

CARL HERING GEORGE F. SEVER,
Chairman, Official Representative.
Committee on Resolutions.
February 6, 1912.

The New York Party of the Panama Convention of the American Institute of Electrical Engineers tenders its thanks to the following for their services in providing entertainment for the party while on board the S.S. Almirante:—Messrs. G. S. Rose, A. H. Lawton and A. P. Palmer for arranging the athletic sports; Messrs. G. M. Bates, A. H. Lawton and Dr. J. F. Hadley for vocal and instrumental music; Dr. A. C. Humphreys and Mr. W. W. Freeman for leading divine service.

CARL HERING, GEORGE F. SEVER,
Chairman, Official Representative.
Committee on Resolutions.
February 6, 1912.

The members of the Panama Convention of the American Institute of Electrical Engineers take pleasure in expressing their thanks to the committee on finance consisting of Messrs. C. A. Greenidge, chairman, A. H. Lawton, M. E. Leeds, R. F. Schuchardt, M. H. Gerry, Jr., and J. C. Smith, for the very able and successful work done by it.

It was a great pleasure and surprise to see how much the committee accomplished with the funds collected to meet the cost of the various trips as well as the special train service on the Canal Zone and the reception and dance given to the officers and engineers of the Canal Zone and the Tivoli Club.

CARL HERING, GEORGE F. SEVER,
Chairman, Official Representative.
Committee on Resolutions.
February 6, 1912.

The members of the Panama Convention, of the American Institute of Electrical Engineers on board the S.S. Almirante extend their sympathy to Dr. A. C. Humphreys for his accident on the Isthmus which so unfortunately interfered with his further sightseeing, and regret greatly the loss of his genial companionship on deck during the return trip.

CARL HERING, GEORGE F. SEVER,
Chairman, Official Representative.
Committee on Resolutions.
February 6, 1912.

We, the members of the Panama Convention of the American Institute of Electrical Emgineers, on board the S.S. Almirante, feel that our pleasure, comfort, enjoyment, entertainment and feeling of safety while on board this ship, have been so greatly enhanced by our genial Captain H. A. Henshaw, commander of his Company's fleet, that we take great pleasure in tendering him our sincere feeling of appreciation of his unceasing, sincere and hearty interest in our welfare, his personal courtesies and the excellent care which he personally takes of his ship.

CARL HERING, Chairman, Committee on Resolutions.
GEORGE F. SEVER, Official Representative.
February 6, 1912.

The Members and Associates of the American Institute of Electrical Engineers participating in the Panama Convention of 1912 suggest to the Board of Directors that in view of the fact that the Panama Canal will be formally opened in January, 1915, and further that an International Electrical Congress will be held in San Francisco in the summer of the same year, a convention be authorized to consist of a sea voyage on a chartered steamer from New York to San Francisco and return via the Panama Canal and of sessions at the San Francisco Exposition.

CARL HERING, Chairman, Committee on Resolutions.
GEORGE F. SEVER, Official Representative.
February 6, 1912.

Resolved that we, the members of the Panama Convention of the American Institute of Electrical Engineers and our guests, appreciating the untiring efforts necessary to carry out the splendid and comprehensive plans and the execution of every detail required to make our trip comfortable, enjoyable and instructive, desire to express our sincere thanks to the general committee, and to Prof. G. F. Sever in particular for the effective work which has been done.

CARL HERING, Chairman, Committee on Resolutions.
February 6, 1912.

To the Ladies of the Panama Convention of the American Institute of Electrical Engineers:

At a formal meeting of the bachelors, husbands, and husbands to be or not to be, held on the S.S. Almirante, February 5, 1912, it was unanimously agreed that without the Ladies the delightful social features of the trip would have lost their chief charm, and that due recognition should thus be recorded of their uniform good nature, endurance and enthusiasm throughout the entire trip.

CARL HERING, Chairman, Committee on Resolutions.
GEORGE F. SEVER, Official Representative.
February 6, 1912.

It is well to note here, that the Board of Directors at its meeting on February 9, 1912, designated the Panama Canal Trip the "Panama Convention."

Throughout the whole trip the largest spirit of loyalty to the A.I.E.E. was manifested and no untoward incident marred this three weeks' sojourn on the ships and on the Isthmus. Some interesting statistics of the attendance are appended.

INTERESTING DATA REGARDING COMPOSITION OF PARTY AND ATTENDANCE ON TRIPS ON ISTHMUS

Title		Almirante	Cartago	Total	Grand Total
Members		11	5	16	45
Associates		18	11	29	
Members' Ladies		5	3	8	13
Associates' Ladies		4	1	5	
Boy			1	1	1
Guests	Men	15	25	40	51
	Women	5	6	11	
					110

$\frac{45}{110}$ = 40.9 per cent of party composed of Members and Associates of A. I.E.E.

$\frac{45}{7200}$ = 0.625 per cent of total membership at Convention.

SPECIAL TRAIN ATTENDANCE

Date	Number on Train	Guests	Number of Party
Thursday, Jan. 25	110		
Friday, Jan. 26	131–128	11 officials 1 guest	119
Saturday, Jan. 27	123-122	7 "	116
Sunday, Jan. 28	92	9 "	83
Monday, Jan. 29	123	7 " 10 guests	106
Tuesday Morn, Jan 30	63		
Tuesday Afternoon Jan 30	69		
Thursday, to Colon, Feb. 1	105		
	714		

George F. Sever.
Official Representative.

PROCEEDINGS

of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

SECTION II

Papers, Discussions and Reports

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A paper to be presented at the Pittsburg Meeting of the American Institute of Electrical Engineers, April 25-27, 1912.

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(Subject to final revision for the Transactions.)

ELECTRIFICATION OF A REVERSING MILL OF THE ALGOMA STEEL CO.

BY BRADLEY T. MCCORMICK

General Description

The Algoma Steel Company of Sault Ste. Marie, Ont., Canada, has recently put into operation an electric reversing mill equipment operating the blooming mill. The mill is required to roll 75 tons per hour from ingots 20 in. (50 cm.) by 20 in. (50 cm.) into billets 8 in. (20 cm.) by 8 in. (20 cm.) in 15 passes.

The electrical equipment (see Fig. 1,) is in a separate building from the mill, with an opening in the wall to permit connection between the mill motors and the rolls, while in the mill room, in a position convenient to the operator, are placed the operating controller and an instrument column carrying meters showing the current, voltage, and speed of machines.

The rolls are driven by two 600-volt direct-current .motors mounted on the same shaft. Each of these motors has a normal rating of 2,000 h.p. at 75 rev. per min., and their armatures are connected in series across 1,200 volts. The current for the motors is supplied by a flywheel motor-generator set consisting of two 1,700-kw. 600-volt direct-current generators, with their armatures also connected in series, driven by a 25-cycle, three-phase induction motor of 1,800 h.p. capacity, at 375 rev. per min. synchronous speed. A 150,000-lb (68,000-kg.) flywheel serves to equalize the load, so that the power drawn from a 25-cycle line is kept practically constant at a value corresponding to the average power required by the rolling mill motors. An idea of the construction of the flywheel motor-generator set can be gained by reference to Fig. 3.

As the power demand at the rolls rises and falls, a slip regulator automatically inserts or cuts out resistance in the rotor circuit of the induction motor, thus providing sufficient speed variation of the motor-generator set to enable the flywheel to alternately deliver and absorb energy in such a way as to make the load on the 25-cycle power line practically uniform. When the power demand of the roll motors exceeds the average, the resistance in the rotor of the induction motor is increased. This decreases the speed of the motor generator set, preventing a rush

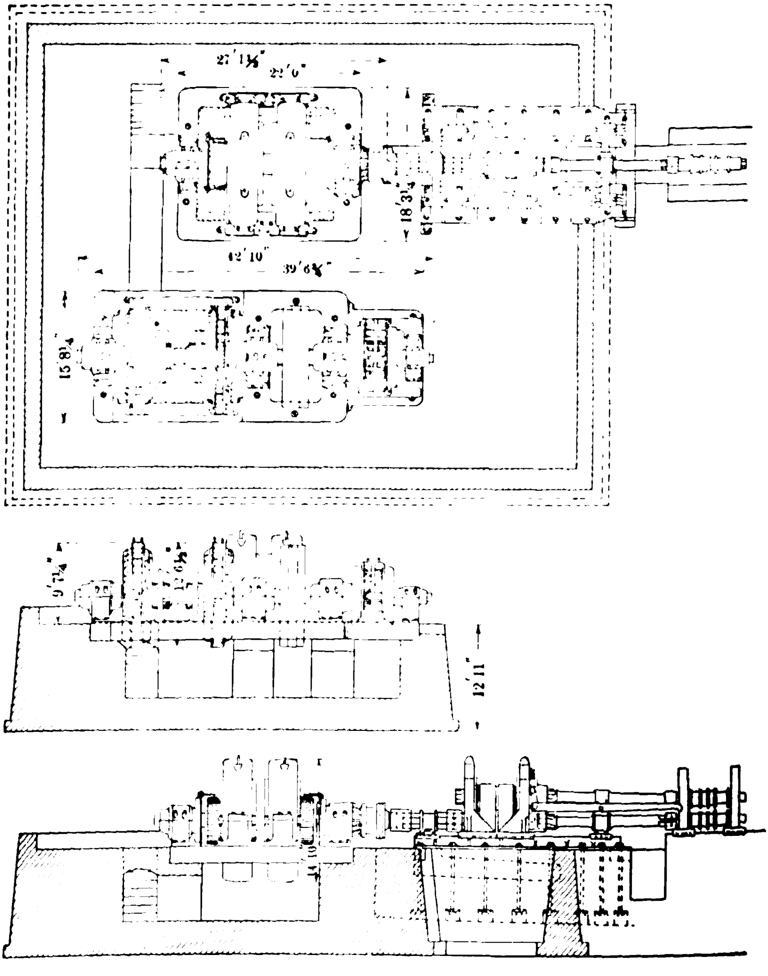


FIG 1.—ROLLING MILL EQUIPMENT

of current from the alternating-current line, and at the same time allowing the flywheel to give up part of its stored energy to carry the mill motors over the peak load. When the power demand is light, the resistance is cut out of the rotor circuit, allowing the induction motor to speed up the set and store energy in the flywheel.

From the foundation plan it will be noted that under both the motor-generator set and the mill motors pits are provided in order to give easy access to the underside of the machines where the leads are connected to the terminal boards. These pits also provide a place for locating series shunts, resistances, etc., which would be very unsightly if placed above ground. The opening under the motor-generator set is connected to the one beneath the motor by a passage way, and is reached by a stairway leading from the main floor.

The speed control and the reversal of the mill motors are effected by varying the voltage impressed upon their armatures through rheostatic control of the fields of the generators.

The excitation for both the mill motors and the generators is supplied by a 40-kw. 250-volt induction motor-generator set. Fig. 8 shows the complete connection diagram for the equipment. The direct-current circuit is protected by a relay in series with the armatures of the generators and mill motors. When the current exceeds the setting of the relay, the latter opens an auxiliary circuit, tripping the circuit breaker in the field of the 40-kw. exciter, thereby killing the excitation on all the direct-current machines.

MILL MOTORS

Since the requirements of a motor drive for a reversing mill demand frequent reversals from full speed in one direction to full speed in the opposite direction in a very short space of time, it is of the utmost importance that the moving parts should be so designed as to obtain the minimum amount of inertia. To accomplish this result, the rolling mill drive was divided into two units, as shown in Fig. 2, mounted side by side on the same shaft and base. Each unit has a normal rating of 2,000 h.p. at 600 volts and 75 rev. per min., with a maximum rating of $2\frac{1}{2}$ times normal, giving a total maximum of 10,000 h.p. available at the rolls for short intervals. This corresponds to a maximum torque of 700,000 pounds (317,500 kg.) at one foot (30.48 cm.) radius.

The motors have 16 poles and are of the interpole type. They are also provided with compensating windings in the pole faces of the main poles, in order to reduce the distorting effect of the armature reaction upon the field which would otherwise become quite marked on the peak loads. The yokes are of cast iron, while the main poles and interpoles are of laminated steel punchings. The fields are wound of strip copper on edge in two layers with a duct between to afford an air passage for ventilation. Fig. 4, reproduced from a photograph of the lower half of one of the motor yokes, taken during the process of assembling, shows the construction of the fields. The fields are each separately excited from the 250-volt exciter mains, while a regulating resistance in series with each field circuit gives an adjustment by which the motors may be made to equally divide their load, in case of any slight difference which may exist between the saturation curves of the two machines.

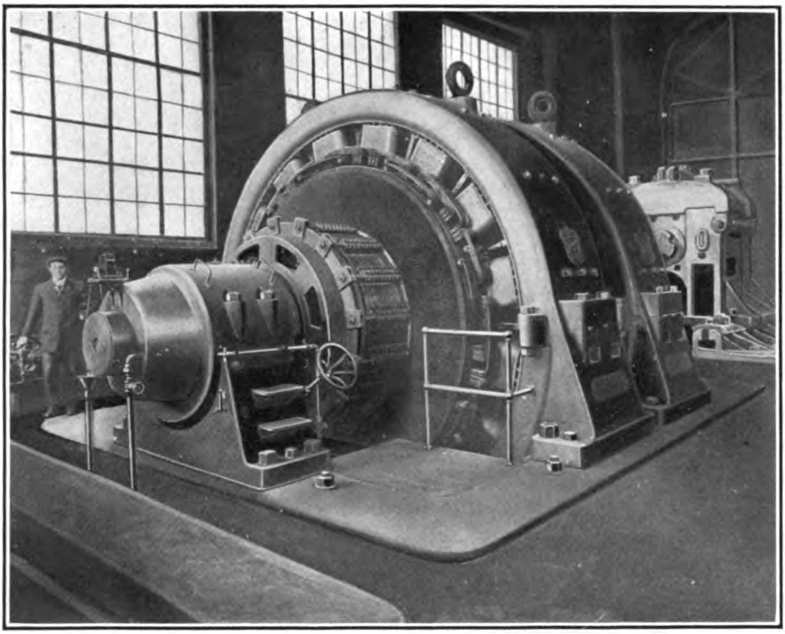
The motor armatures are connected in series and are designed for a normal pressure of 600 volts, but by varying the value and direction of voltage impressed across the armatures, the motors, can be made to run in either direction at any speed up to 75 rev. per min.

In order to withstand the severe mechanical stresses set up by the rapid reversals of rotation and the shocks transmitted from the rolls, it was necessary to make the spider and commutator of the most rigid construction. The bearings are protected from end thrust by a thrust collar mounted on the bearing pedestal next to the rolls (see Fig. 7). One side of the collar is of babbitt and the other of steel. Grease is used for lubricating and is fed by compression grease cups.

DIRECT-CURRENT GENERATORS

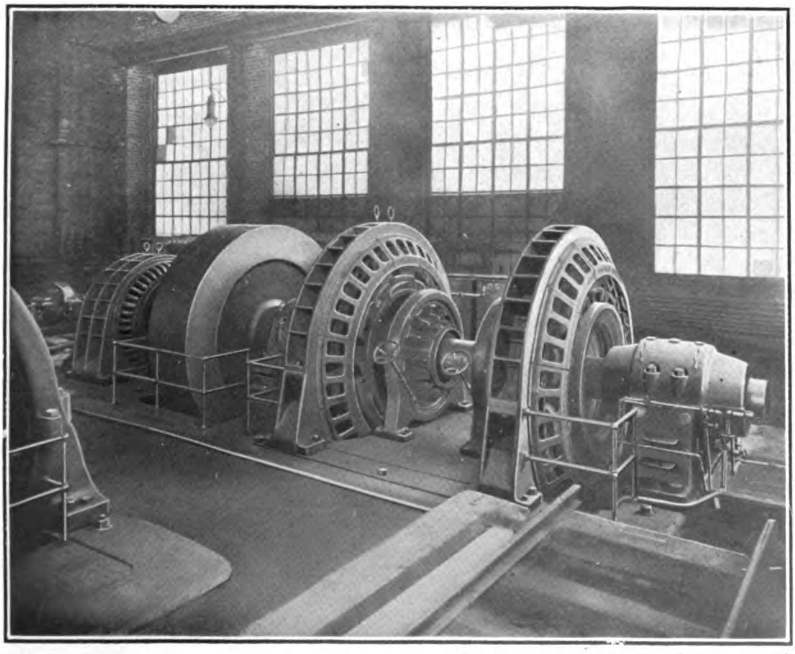
The generators each have a normal rating of 1700 kw. at 600 volts with a no-load speed of 375 rev. per min. The armatures are connected in series, giving 1,200 volts across the two machines. They are capable of carrying an overload of 2½ times normal, corresponding to the overload of the mill motors. The generators are also of the compensated interpole type, but the magnetic circuit is entirely of a laminated steel, in order that the field may respond quickly to variations in excitation. Fig. 5 shows a portion of the generator during the process of construction.

The commutators are of the open neck type and are constructed in such a way that the air passes through the spiders of the machines, coming out through the commutator necks, and



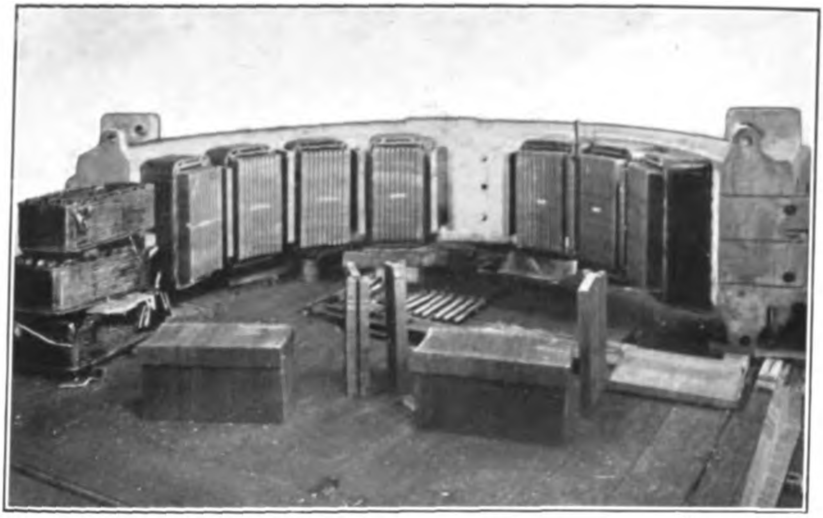
[MC CORMICK]

FIG. 2.—2000-H.P. MILL MOTOR



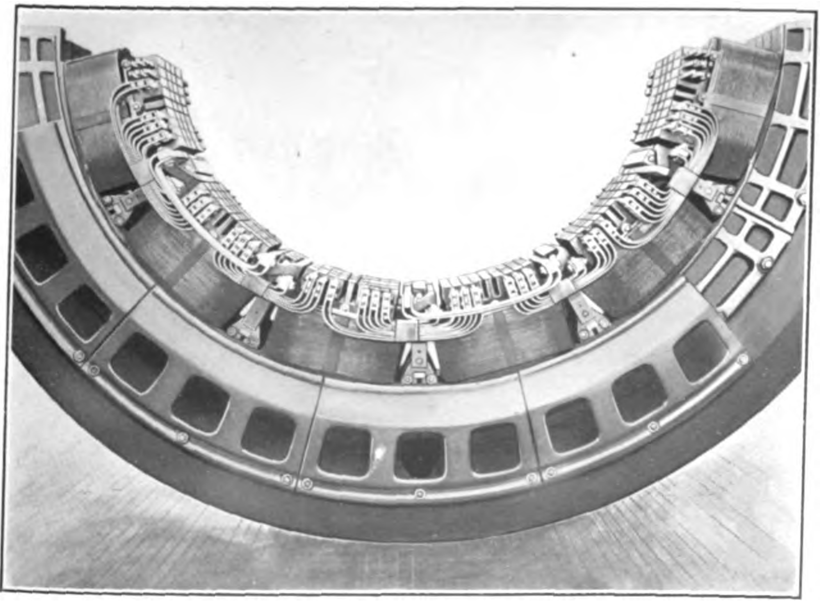
[MC CORMICK]

FIG. 3.—FLYWHEEL MOTOR-GENERATOR SET.



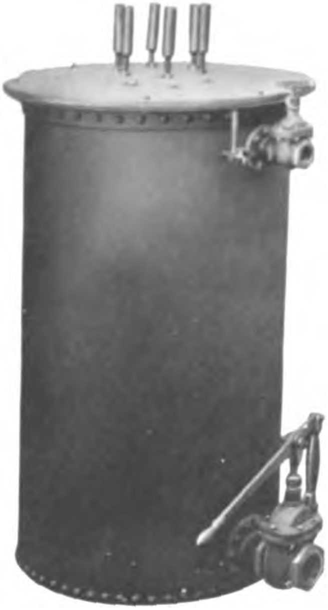
[MC CORMICK]

FIG. 4.—2,000 H.P. MOTOR UNDER CONSTRUCTION



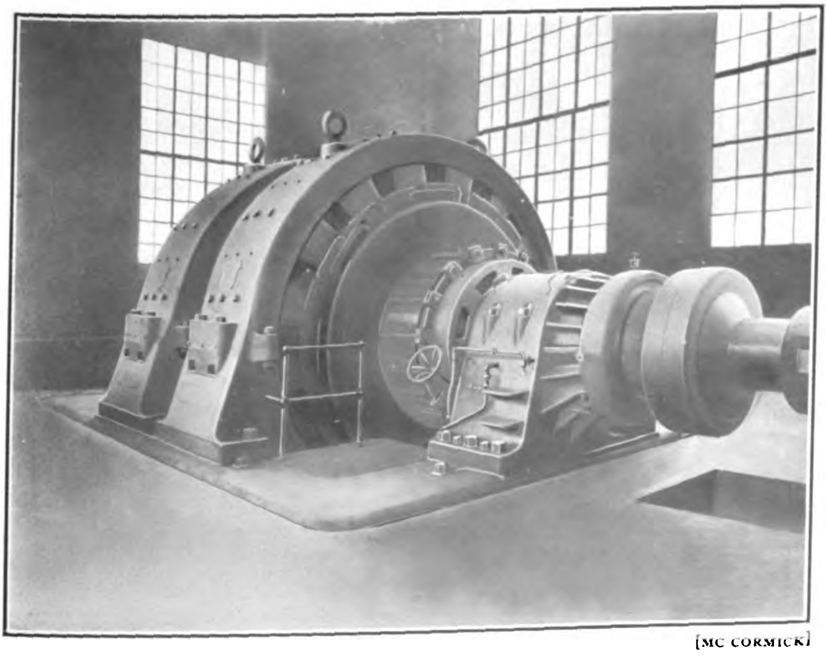
[MC CORMICK]

FIG. 5.—1,700 KW. GENERATOR UNDER CONSTRUCTION



[MC CORMICK]

FIG. 6.—WATER-COOLED STARTING RESISTANCE



[MC CORMICK]

FIG. 7.—2,000 H.P. MILL MOTORS, SHOWING THRUST BEARING.

blows across the face of the commutators. No other source of ventilation is necessary to cool the commutators. As any vibration of the brush rigging is very objectionable on commutators of such high peripheral speeds, the brush mechanism is supported on a separate yoke mounted on the base plate.

The fields of the two generators are connected in series and excited across the 250-volt exciter mains, and controlled by a rheostat of such construction that the excitation can be reversed and varied by small steps over any range between zero and the maximum. This rheostat is mounted in the mill room and is under the control of the man operating the rolls.

Induction Motor and Flywheel

The induction motor has a rating of 1,800 h.p., 2,200 volts, three-phase, 25 cycles, at 375 rev. per min. synchronous speed. It is of the wound secondary type, in which the current from secondary, or rotor, is carried out through slip rings to the slip regulator. As there is nothing special in the construction of the motor, it requires no further description. The flywheel is 12 feet (3.65 m.) in diameter, and is made of cast steel in three pieces, carefully machined on the rim and held together by fitted bolts passing through reamed holes.

Bearings and Lubrication

It can readily be seen that the requirements of the bearings for the motor-generator set are somewhat more severe than are usually met with in electrical machines of the ordinary type. The heavy weight to be sustained by the bearings on either side of the flywheel requires considerable bearing surface, and necessitates a large bearing diameter with correspondingly high velocity of rubbing, in order that the bearings shall not be unreasonably long. The combination of high bearing pressure and peripheral speed requires the most careful design to secure perfect lubrication. All of the bearings, both on the motor-generator set and on the mill motors, are self aligning, and provided with water cooling and three distinct methods of lubrication, ring oiling, oil flooding and presssure lubrication. Under ordinary running conditions the pressure lubrication can be dispensed with, but it is very useful in starting. When the motor generator set comes to rest the oil film is squeezed out of the bearings, and unless this film can be established again before starting, a torque of about 60,000 lb. (27,200 kg.) at one foot

(30.48 cm.) radius would be required to move the set from rest. But starting the oil pump soon establishes a film again so that the set will begin to revolve on the first step of resistance and come smoothly to full speed without any abnormal demand on the power station.

A small motor-driven oil pump furnishes the oil for both the flooded lubrication and pressure lubrication systems. The overflow from the bearings passes through a cooler and filter and then is pumped up into a storage tank from which it flows by gravity into the bearings. Valves are provided so that the oil can be by-passed around the cooler, filter and storage tank, and be pumped direct into the bearings under pressure, when starting.

STARTING APPARATUS

The rotating parts of the motor-generator set revolving at 375 rev. per min. have a kinetic energy of 85,000,000 ft-lb. (11,755,000 kg-m.) During the period that the set is being brought to full speed, the resistance in the rotor circuit of the induction motor is required to absorb this amount of energy. In order to dispense with a bulky cast iron grid resistance, a special water-cooled resistance was used (See Fig. 6). This resistance consists of a boiler iron tank with a water inlet valve at the top connected to the water mains, and a quick opening gate valve at the bottom for an outlet. The resistance element is immersed in water and consists of a hollow iron tube of helical form, with the taps for the various starting positions, leading out through the top of the case. During the starting period the energy absorbed by the resistance is transferred to the water, after which the hot water can be emptied at the bottom and the tank refilled ready for starting once more. The tank was designed with a water capacity sufficient to absorb 85,000,000 ft-lb. (11,755.000 kg-m.) of energy, with an additional allowance in case the motor generator set should, at some time, refuse to start immediately and the current remain on for several minutes before the set commenced to revolve. The steps of resistance are cut out by six short-circuiting switches, of the manually operated, multiple lever type, mounted on the switchboard.

AUTOMATIC SLIP REGULATOR

For the purpose of varying the slip of the motor-generator set, cast iron grid resistance is used, made up of three steps automatically switched in and out of circuit by slip regulators.

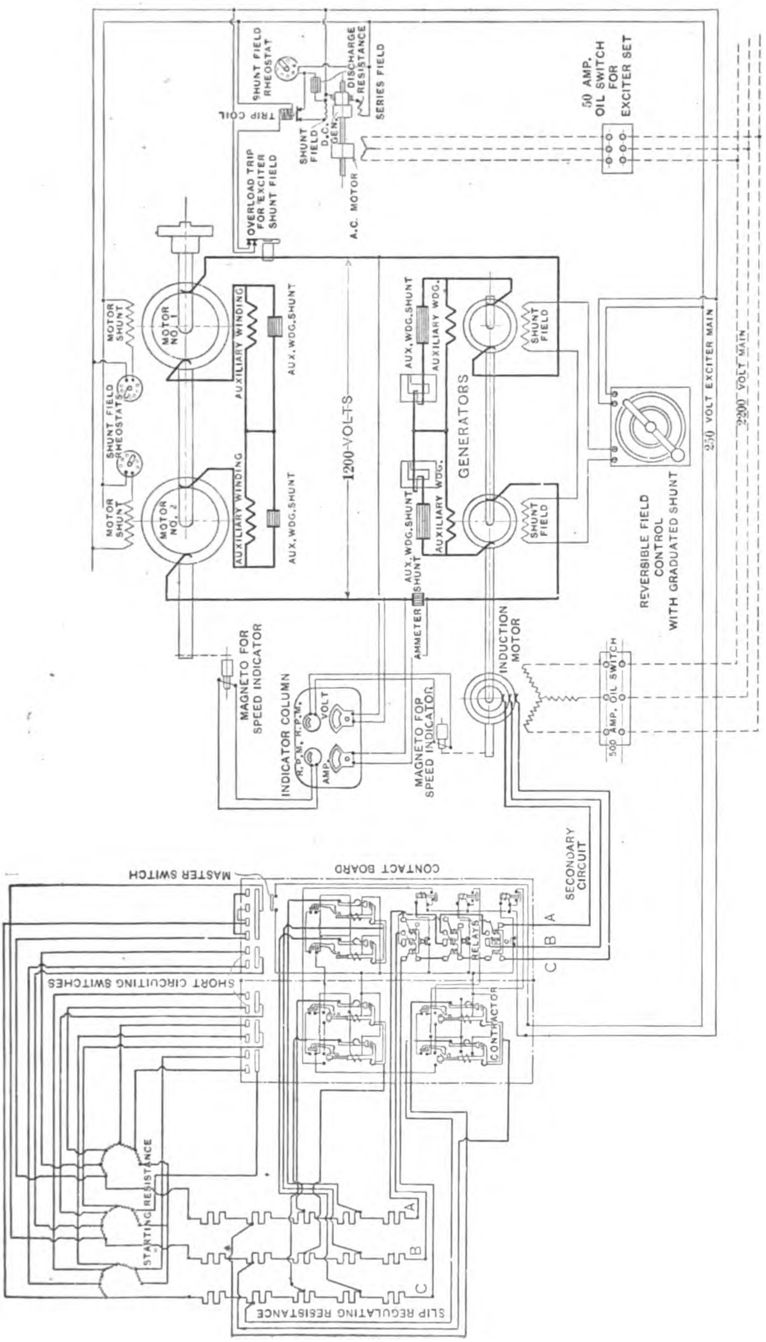


Fig. 8—Diagram of Connections for Rolling Mill Equipment

Each element of the slip regulator consists of a series relay and a contactor switch. The contactor switch is operated by direct-current solenoids on the 250-volt exciter main and is actuated by the opening and closing of the series relay. When the current in the rotor exceeds a certain fixed amount, the series relay breaks the current in the solenoid of the contactor switch, allowing it to open and insert resistance in the rotor circuit of the induction motor, thereby reducing the current and increasing the slip. These switches are interlocked in such a way that they will operate one after another in the proper order.

It was hoped that it would be possible to embody in this paper some figures showing the results of a test on the plant, but unfortunately the curve-drawing instruments to be used were not available early enough.

The equipment has been in operation, rolling steel, since December 10, 1911, and the results obtained indicate that the machines are well within the requirements, and that the mill motors are capable of being reversed with sufficient rapidity to easily meet any requirements in rolling. In a rough test made in order to determine the length of time required to reverse the motors, 22 reversals were made in one minute at 75 rev. per min., with the voltage on the 250-volt exciter mains reduced to 200 volts. The complete results of the test were not at hand in time for inclusion in the paper.

A paper to be presented at the Pittsburg Meeting
of the American Institute of Electrical Engineers,
April 25-27, 1912.

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(*Subject to final revision for the Transactions.*)

SELF STARTING SYNCHRONOUS MOTORS

BY CARL J. FECHHEIMER

The following treatment of the starting of synchronous motors is intended to apply to polyphase motors and has been worked out for those of the revolving field type, but can doubtless be so modified as to apply to motors of the revolving armature type as well. The analytical treatment of the subject applies to motors with definite pole construction. The writer has not investigated in any way starting of motors of the round rotor type, such as are used in the construction of large high-speed turbo-generators.

In polyphase induction motors the starting torque is proportional to the product of current in phase with the flux multiplied by the flux. The simplest example of this is that of a two-phase motor in which the torque is produced by the flux arising from the magnetomotive force of phase one multiplied by the component of current in phase two which is in time-phase with the flux. As the flux is in time quadrature with the impressed electromotive force of phase one and the conductors in phase two lie in this flux, it will be seen that the component of current in phase two which is productive of torque is the component which is in time-phase with its impressed electromotive force; in other words the starting torque is proportional to the power input to the rotor. As has often been demonstrated with induction motors, the starting torque expressed in synchronous watts is equal to the power input to the rotor expressed in true watts.

The same principle can be shown to apply in a similar way to three-phase machines; but the truth of this has been so well established and realized by all who have designed induction motors, that the validity thereof can, without further proof, be well appreciated by those who are familiar with the phenomenon referred to.

When a polyphase electromotive force is applied to the stator of a synchronous motor it produces a rotating field in the same manner as is the case with an induction motor. If the rotor be stationary, electromotive forces are induced therein, which in turn cause currents to flow, the values of which depend upon the electromotive forces and the impedances of their paths.

If the entire rotor structure be well laminated, these currents are so small in magnitude that they will have little reaction upon the flux which produces them. On the other hand, if the poles only are laminated and the field ring made solid, of steel or cast iron, the currents will then be in the form of eddies in the solid structure. These currents, being induced by transformer action between the stator and the rotor, must react upon the stator and cause currents to flow in the stator conductors which have magnetomotive forces equal and opposite to those which flow in the rotor. If the characteristics of the solid rotor were such as to cause the eddy currents induced therein to lag 90 degrees behind the electromotive forces which produce them, then it will be seen that the stator currents, the magnetomotive forces of which are opposed to those in the rotor, are also in time quadrature with the stator equivalent of electromotive forces induced in the rotor.

In starting a synchronous motor by applying voltage to the stator, the same conditions obtain as in the induction motor. In other words, to secure any starting torque, it is essential to have currents in the rotor lagging less than 90 degrees behind the electromotive forces which produce them.

It is only a small step from this to the case of the synchronous motor with a solid field ring, laminated poles and squirrel cage or amortisseur winding; that is, the starting torque is proportional to the components of the currents in the rotor circuit which are in phase with the electromotive forces that produce them, regardless of whether the currents are in the field ring, in the amortisseur winding, in the rivets which hold the poles together, or in the collars around the poles. If we have a laminated rotor body, we confine nearly all the in-phase currents to the amortisseur winding and collars around the heads of the poles, if such are used. In this latter case we may regard the torque as being produced by the components of the currents in the rotor bars which are in phase with the flux. The other conception of the manner of production of torque is that the in-phase components of the currents in the stator conductors, the magnetomotive forces of which neutralize the in-phase currents in the rotor, act with the flux to produce forces at the periphery. As the stator is secured in position, the rotor starts to revolve.

It will also readily be seen that were the rotor to have solid poles instead of laminated, the same general principles would apply. Due to the large reaction of the eddies which are induced in the solid pole shoes in this latter case, the flux does not penetrate into the pole body to nearly so great an extent as is the case with laminated poles; that is, the eddy currents which are induced in the poles tend to keep the flux from entering them, producing the well-known skin-effect phenomenon.

Upon the foregoing principle are based all of the calculations and derivations of formulae in this paper; that is, we have only to determine the power input to the rotor and we at once obtain the starting torque. In order to verify this, a number of experiments have been conducted on machines with laminated poles, cast steel field rings, with and without amortisseur windings; and also on machines with solid poles, solid field rings and solid pole shoes. The torque was measured by means of a brake and due allowance was made for discrepancies caused by the static friction of the bearings.

The power input to the stator was measured by means of wattmeters, the current was measured by ammeters in all phases, and the electromotive forces measured across all phases. The power input to the rotor was determined by deducting the stator copper loss from the stator input. In comparison with the stator copper loss, the core loss was so small that it could be neglected. There were, to be sure, certain points of difference, in some cases the starting torque being slightly greater than obtained by deducting the loss in the stator from the power input, and while in other cases it was slightly less, the discrepancy in general was about the same as is obtained when making starting torque tests on induction motors. For further discussion of this point, see " Non-Uniformity of Torque at the Instant of Starting," " Unbalance in Phases," and " Star and Delta Connection."

One apparent source of error, which cannot be neglected, was the marked effect of variation in starting torque with different positions of the rotor. It was found, however, in general, that the average starting torque agreed very well with the power input to the stator minus the losses in the stator.

From the above it will be seen that in order to secure large starting torque with small currents from the line, it is essential:

1. To make the losses in the rotor high by using relatively large resistances.

2. To minimize the reactance due to leakage fields which interlink with currents induced in the conductors in the rotor at the instant of starting.

3. To reduce as much as possible the reactance due to leakage fields in the stator, as these greatly increase the electromotive force which it is necessary to impress upon the stator.

4. To make the magnetomotive force required to drive the flux across the air gap as small as is consistent with the good performance of the motor after it is under operating conditions. The beneficial effects upon starting conditions secured by reducing the air gap are not, in the writer's opinion, so great as some believe. See also "Comparison between Induction and Synchronous Motors at Starting."

5. To reduce as much as is consistent with first cost and performance, the resistance of the stator windings. This not only reduces the electromotive force required to produce the requisite starting torque, but also lowers the power input to the motor during the starting period.

The five factors given above are in the order of their importance according to the writer's judgment.

To facilitate the reading of the paper, the derivations of such formulae as may be useful in the final calculation of the starting conditions, but which do not lead directly to the derivation of the final equations, have been appended. This applies to the derivation of the equations for leakage reactances and for the convenience of the reader the final results are repeated in the main body of the paper.

SELF AND MUTUAL INDUCTION

With the rotor of a synchronous motor stationary, the circuits are essentially those of the primary and secondary of a transformer with great leakage between its members and large magnetizing current. The secondary is short circuited in that the currents are caused to flow through the amortisseur winding, or in the solid masses in the form of eddies.

The values of these currents must be equal to the voltages induced, divided by the impedances of their paths, and the time-phase position in every case is such that the tangent of the angle of lag of each current behind its voltage is equal to the reactance divided by the resistance. In other words, we must consider the relations of the same factors which obtain in a transformer with a short circuited secondary.

It has been found from numerous tests that the apparent inductance of coils lying in slots opposite the pole heads is greater than that of those lying between the poles. It would appear from this that the self-induction of the former is greater than that of the latter. With an amortisseur winding on the rotor, this is true to a limited extent only. Emanating from those coils opposite the pole heads leakage fluxes from the teeth pass into the heads of the poles without interlinking with any of the rotor conductors. This is entirely leakage flux which we designate as zigzag leakage. There is, however, an additional flux which does interlink with the rotor conductors and would apparently increase the inductance of the stator, inasmuch as the current for the same voltage is decreased thereby. However, this flux produces mutual, rather than self-induction, and may be productive of torque, whereas the self-inductive flux has the effect of increasing the drop in the stator without assisting in the production of torque.

Tooth tip leakage, which we have distinguished from the zigzag leakage, arises from those coils which lie in slots between the pole heads. Tooth tip leakage has air only for its path, whereas zigzag leakage has the air gap and part of the pole head for its path. Were it not for the mutual flux, which in general is productive of torque, the apparent reactance would not be very different for the various positions of the rotor. This will be seen at once, when one considers that a great portion of the leakage of the stator is made up by the flux which crosses the slot and that which encircles the end connections.

If the rotor be not provided with an amortisseur winding and the poles and field ring be so well laminated that no appreciable currents flow in any parts thereof, a large flux will pass through the poles and field ring and will cause a larger apparent reactance in the coils opposite the pole heads than in the intermediate ones. Since there are negligible currents in the rotor, it would hardly be correct to consider this as mutual flux, but rather as self-inductive flux only. In a similar way, with a solid field ring and laminated poles, the flux which passes as leakage from pole to pole must be considered as self-inductive and not mutual flux. In this case that flux only is mutual which passes into and interlinks with the various conductors carrying eddy currents in the solid field ring.

Inasmuch as the voltage induced in the field coils reaches a very high value with laminated rotor construction, it is evident that the flux which passes through the poles reaches considerable magnitude. This is the mutual flux which is productive of torque and is the chief cause of the unbalance in the currents in the stator. For further discussion of this see. " Non-uniformity of Torque at the Instant of Starting," " Unbalance in Phases," and " Star and Delta Connection."

EFFECTS OF HYSTERESIS

Any loss which occurs in the rotor at the instant of starting will tend to bring the current more nearly into time phase with the flux and thus materially assist starting. Whether this loss is due to hysteresis or currents induced in the rotor is immaterial, as both tend to reduce the angle of lag of the current behind the electromotive force which produces it.

If we were to completely laminate the rotor structure and depend upon hysteresis rather than eddy currents, very little torque would be obtained. It is for this reason that we provide paths through which the currents may flow, which will be influential in producing torque.

The hysteresis loss is so small in general, in comparison with circulating currents, that we may entirely neglect it. This is customary in connection with induction motors and, as is well known, no appreciable error is introduced by following out this method.

NON-UNIFORMITY OF TORQUE AT THE INSTANT OF STARTING

If two pieces of steel or other magnetic material be placed opposite each other and one of them be magnetized so that a consequent pole is induced in the other, then the two pieces will tend to move into such position as to reduce to a minimum the reluctance of the path through which the flux passes in going from one piece of steel to the other.

Applying this principle to the case of the motor in question, it will be seen that if the polar arc has such length that for some positions of the rotor the reluctance of the flux path through the air gap is different from that for other positions, then there will be a variation of torque in the different positions of the rotor for the same input to the stator. It is very important, therefore, in proportioning the parts of the rotor body to make the polar arc of such length that the reluctance of the air gap path will be nearly uniform, regardless of the position of the rotor with respect to the stator. If the rotor should be in the position of minimum reluctance, then the magnetic forces will tend to hold it there, whereas the in-phase currents which flow in the various rotor circuits will tend to produce rotation of the rotor. It will be essential for the forces produced by these currents to overcome the magnetic attraction in addition to the resistances offered to the motion of the rotor before the rotor will begin to turn.

Those who have designed induction motors will appreciate how much the torque will vary for different positions of the rotor, if the number of slots in one member is an exact multiple of those in the other. For example, if we were to take the most striking case of having an equal number of slots in the stator and rotor, then the currents flowing in the conductors set up magnetic fields which tend to hold the rotor in the position of minimum reluctance; that is, with a tooth in the rotor opposite a tooth in the stator.

Applying this to the synchronous motor, it will be seen that if we were to use a squirrel cage winding with the angular distance between slots in the poles equal to the angular distance between slots in the stator, then the currents which would be produced would likewise tend to hold the rotor in the position of minimum reluctance. The worst case occurs when the rotor bars are exactly one stator slot pitch apart; but there would be considerable variation in torque nevertheless, if the bars were spaced one-half slot pitch, or two slot pitches, or any other multiple of the stator slot pitch.

It is well known, in general, that the variation in starting torque is minimized in induction motors if the rotor resistance is high compared with its reactance. In other words, the forces due to the in-phase current become large compared to those produced by magnetic attraction between the rotor and stator. For example, slip-ring induction motors, which have 50 per cent variation in starting torque with the rotor short circuited, have nearly uniform torque with such resistance in series with the rotor as to give normal full load torque at starting.

This applies also to the case of synchronous motors. The writer knows of a certain motor in which the tendency to have locking points due to this source would have been very great, but which in point of fact amounted only to 14 per cent, chiefly due to the fact that the squirrel cage winding was of high resistance as compared with the rotor reactance.

If the spacing between the rotor bars is not a multiple of the stator slot pitch, the air gap being small and the stator slots large, there may be a tendency for the bars to heat unduly when the motor is in synchronism, as the result of the variation in flux between the bars caused by the tufting from the stator teeth. To space the bars other than a definite multiple of the stator slot pitch may create considerable losses and excessive temperature rise. To determine the spacing of the bars in the poles, the designer should call upon his judgment.

There is one other case of which the writer knows that may produce a large variation in torque for the same input to the stator, which is given under " Star and Delta Connection " and will not be repeated here.

UNBALANCE IN PHASES

It is evident that the coils in the stator, which at the instant of starting are directly opposite the pole faces, will have more flux interlinked with them than those coils which are between the poles. This will produce a greater counter electromotive force per ampere in those coils which are opposite the poles than in those between the poles and therefore less current will flow in the former than in the latter. It will be seen, therefore, that the phases are badly unbalanced at the instant of starting in any definite pole synchronous motor.

As tests which have been made upon motors at rest indicate that this apparent reactance frequently varies about 50 per cent between the two positions, the currents will be correspondingly unbalanced, although not to the same extent that the reactance is greater in one extreme than in the other.

The unbalance in currents also causes an unbalance in impressed electromotive forces, the extent of which is not only dependent upon the difference between currents in the various phases, their magnitude and power factor, but also upon the voltage regulation of the source of supply. In general, the more the impressed electromotive forces are unbalanced by the currents, or the poorer the regulation, the less will the currents be unbalanced.

If the stator be wound with the usual six-phase winding connected for three-phase star—that is, if each phase belt be distributed over 60 electrical degrees—then it will be possible for two of the phase belts to be directly opposite the poles and the third phase belt to be between the poles so that the current which flows in the phase between the poles will be considerably greater than the currents in the other two phases.

By using the ordinary three-phase winding and connecting it star—that is, using a winding in which each phase belt is distributed over 120 electrical degrees—the unbalance would in all probability be much less. However, this method of winding is hardly to be recommended, as the motor would thereby be handicapped in many ways.

In all the calculations which are made, the final value of current obtained is the r.m.s. value of the currents in the various positions and in the different phases. The same applies to the electromotive forces. In working up results from tests, the r.m.s. value was used rather than the average for all currents and electromotive forces.

In the case of three-phase machines the input in volt-amperes was taken to be the product of the square root of three, the r.m.s. values of the currents and the electromotive forces.

The unbalance would in all probability be considerably greater if delta connection were used. This is taken up under the next subject.

One effect of the unbalance in phases would be to cause the rotating field to depart from one of constant magnitude and thus to some extent lower the starting torque. It is well known that anything which upsets the uniformly rotating field may give rise to losses which do not assist toward producing starting torque. This is one of the discrepancies which the designer must continually have in mind when he proportions the parts of the motor with a view of obtaining good starting conditions.

STAR AND DELTA CONNECTION

If the stator is wound for three-phase and each phase belt covers 60 electrical degrees—that is, if the winding is six-phase rather than three-phase—and the connections are star, then the low apparent reactance of one phase as compared with the others will not cause so much unbalance in currents as would be the case were the electromotive forces applied to each phase on each leg individually. For example, if the phase belt of one of the phases is between the poles and the other two phase belts are opposite the poles, the higher reactance of the latter two phases will influence the current in the first phase and prevent its reaching so high a value as would be the case were the neutral point of the motor connected directly to the neutral point of the transformers or generator. This will cause the rotating field which is produced to be more nearly constant in magnitude than would be the case were the phases very badly unbalanced by connecting to the neutral point, with the net result that starting conditions would be much better with star connection and three leads than would obtain with star connection and the neutral connected to the neutral of the source of supply.

If the stator be delta connected, then it would be possible for one phase belt lying between the poles to have comparatively small reactance and have the current in that portion reach a relatively high value. The currents in the other phases, due to the high reactances of their paths, would be low. The result of this bad unbalance would be poor starting conditions in some positions of the rotor and good starting conditions in others. It will be seen therefore that in general delta connection should, if possible, be avoided for self starting synchronous motors, unless the machine be connected star during the starting period. Tests on a delta connected stator bear out the statements made in reference to the large unbalance and great variations in torque.

In general it is assumed that phase belts cover 60 electrical degrees. This, however, does not apply to real three-phase windings in which the phase belts cover 120 electrical degrees, such as are used in three-ring synchronous converters. In these, unless the pole enclosure be small, some of the conductors in each phase must be under portions of the poles, regardless of the relative positions of poles and armature. The unbalance, therefore, is by no means so great as with a six-phase winding, delta connected, and the starting conditions are much improved due to a more uniform torque in the various positions. The writer has not investigated starting characteristics with this type of winding.

In the calculations given in this paper no allowances have been made for the use of delta connection which may unbalance the phases so badly as to make the starting torque less than the power input to the stator minus the losses in the stator. For further discussion of this point, see " Unbalance in Phases."

HIGHER HARMONICS

As has frequently been noted, the higher harmonics in induction motors may produce a rotating field in the opposite direction to that of the fundamental and thus either materially reduce the starting torque or actually cause the rotor to revolve in the reverse direction. They may also cause the rotor to reach a certain fraction of synchronous speed, at which point the higher harmonics may have such an influence as to prevent the rotor accelerating beyond that point.

So far as could be determined, in all synchronous motors on which we have made tests we have not found any one in which the torque at the instant of starting was reduced by higher harmonics. In certain cases, however, when the fields were short circuited, the motors refused to accelerate beyond half speed until their field circuits were opened. This may have been due to the effect of higher harmonics, but we are unprepared at the present time to say with certainty whether or not this was the cause of the reduction in torque at this point. One reason for believing that it may have been due to this cause is that the effect of the higher harmonics is practically eliminated if high resistance is introduced into the rotor circuit. With the fields short circuited, the reactance is extremely high as compared with the resistance, so that the influence of the higher harmonics would be far greater than with the field circuit open.

POLARITY AFTER COMING INTO SYNCHRONISM

After the synchronous motor has been started from rest and locks into synchronism without any current in the field coils, the polarity of the poles in the rotor no longer reverses, inasmuch as the magnetomotive force is produced by currents in the stator and the resultant flux revolves synchronously with the rotor. There is, therefore, a possibility of the polarity being reversed by applying direct current after the motor has come into synchronism. There is about an even chance that the polarity produced by the direct current excitation be the same as that which results after the motor locks into synchronism, as for the reverse condition to obtain.

The magnetomotive force produced by the direct current excitation in opposition to that produced by the alternating current in the stator will cause the flux to drop to zero for a moment and the torque to instantaneously disappear, with the result that the motor will slip a pole and then the two magnetomotive forces being additive, the rotor will remain in this position with respect to the rotating field produced by the stator currents.

This will cause an instantaneous rush of current and may set up mechanical stresses which may be very objectionable, even though they last for a very short period. If the number of poles be large, the instantaneous increase in current and production of mechanical stresses will seldom be serious; if, on the other hand, the number of poles be small, this may be sufficiently objectionable to necessitate precautions being taken. It has been suggested to use a reversing switch for the fields which the operator can manipulate in case the stator ammeter indicates a great rush of current at the instant the field switch is closed. It would of course be essential to use discharge resistance in conjunction with the field so as to permit rapid opening after the circuit has been closed. Another suggestion is to slightly excite the fields shortly before the motor locks into synchronism. This not only insures the motor coming into step, but also increases the torque near synchronism.

Field Connections at Starting

If the fields were short-circuited during starting, a current would flow in them which is nearly in quadrature with the voltage which is induced in them. This will be at once apparent when one considers the fact that the fields have very high reactance as compared with their resistance. This current will have a decidedly detrimental effect upon the starting conditions, as large stator currents must flow to neutralize the magnetomotive forces of the currents in the field coils. These produce large drops in the stator coils and as a result the input to the stator would be much greater for the same starting torque. For this reason the fields should by no means be short-circuited at the instant of starting.

The most favorable conditions, as far as current input for a given starting torque is concerned, would be obtained by placing in series with the field coils a non-inductive resistance which is equal in ohms to that of the reactance of the fields. This, however, is hardly to be recommended, as a rheostat of several hundred ohms, insulated for about double the induced voltage, would be required, and this would be very expensive and cumbersome.

The best method is to leave the fields open, and if this is done the conditions are not much worse than by having in series with the fields a resistance equal to the reactance. The objection to this method is that the voltage induced in the rotor is so high that it may cause the insulation to be punctured. If the fields are wound for 125 volts and insulated for 5000 volts, this voltage is seldom dangerous in this respect.

When the fields are wound for 250-volt excitation or higher, the voltage induced with laminated pole structure may be prohibitively high and heavier insulation may be required on the rotor. With solid poles, however, the voltage induced in the rotor is very much less than with laminated poles, and even when fields are wound for 250 volts and insulated for 5000 volts they are perfectly safe during the starting period. A means for overcoming the danger of breakdown of insulation in synchronous converters with laminated poles has frequently been used and consists in using a field breakup switch which causes the various field coils to be disconnected from one another.

EFFECT OF TEMPERATURE

The currents which flow in the rotor circuit during the starting period cause the rotor conductors to heat considerably. The increase in temperature increases the resistance of the conducting paths, which in turn augments the losses. This increment in losses tends to increase the temperature so that it is essential to take observations very rapidly in order to secure reliable results. This is quite noticeable in its effect upon torque, especially when the pole shoes are made of solid material, such as cast steel, which has a high temperature coefficient.

Readings taken of the input to the stator when the poles were comparatively cold indicate, in general, a lower torque than that which would be obtained by means of a brake, probably due to the fact that less time would be required to take input readings than to take brake readings. This is usually more noticeable when the torque is produced by eddy currents induced in solid metal than when the torque is secured by currents in copper bars in a laminated structure, because in the former the eddy currents are confined to a very thin shell and thus tend to produce excessive local heating in the solid structure; and, secondly, because the change in resistance with temperature is very great for steel or cast iron.

The stator coil temperature is also increased while the static torque tests are being made, and this prevents our determining with accuracy the loss in the stator which should be deducted from the stator input.

RESULTS OF TESTS

Figs. 1 to 6 show the results of tests made on a three-phase generator with laminated poles and cast steel field ring and without armortisseur winding to determine the relations of the various quantities when voltages were applied to the stator with the rotor stationary. These tests were made by the use of a brake and the bearing friction was allowed for and added to the brake readings so as to obtain the total torque produced.

The poles of this machine were so proportioned that the reluctance of the flux path with a slot opposite the middle of the pole was less than that with a tooth opposite the middle of the pole. Since the rotor tends to move into the position of minimum reluctance, it follows that the torque for a given impressed electromotive force is greater with a tooth opposite the middle of the pole than with a slot opposite the middle of the pole. This is shown clearly in Fig. 1.

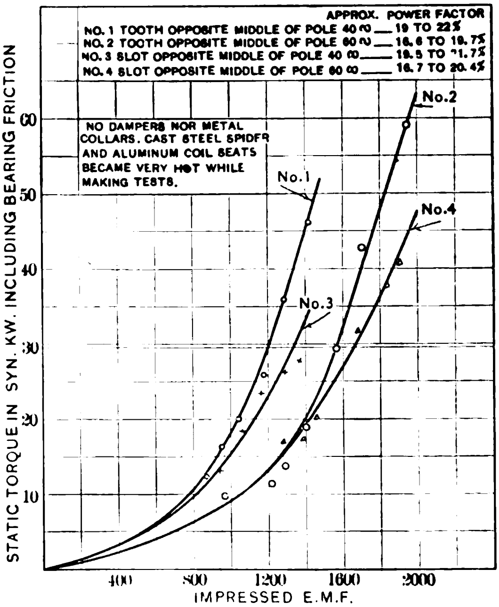

FIG. 1.—VARIATION OF DEVELOPED TORQUE WITH IMPRESSED E. M. F. Without Fields

In Fig. 2 the developed torque is plotted against the stator input minus the stator losses. It will be seen from these tests that the torque in the maximum torque position is greater than the input to the rotor, whereas in the minimum torque position it is less, so that the average is very nearly equal to the rotor input. It will also be observed that the torque is proportional to the rotor input in the minimum torque position, whereas it rises more rapidly than the rotor input in the maximum torque position. This is believed to be due to the incremental torque caused by the magnetic pull brought about by the tendency of the rotor to move into the position of minimum reluctance. It may also be affected by the temperature rise of the solid field ring, which became very hot while making the tests.

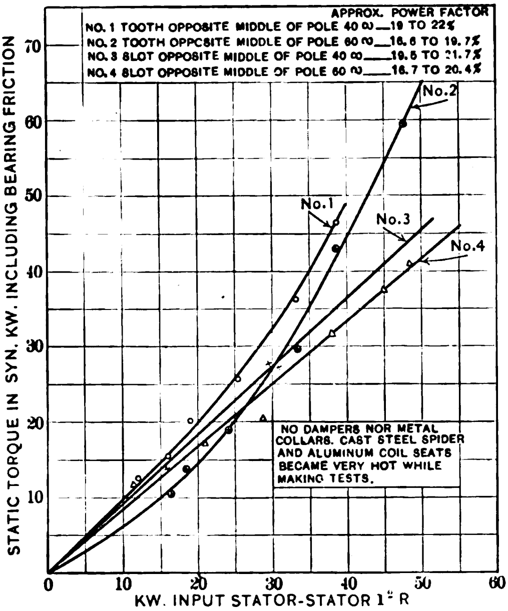

Fig. 2.—Variation of Developed Torque with Approximate Input to Rotor

E. M. F. Varied; Torque Measured with Brake; Without Fields

In Fig. 3 the equivalent of the rotor input is plotted against the resistance which was connected in series with the rotor circuit. The fields were wound for 120 volts direct-current excitation and were connected two-circuit during this test so as to reduce as much as possible the resistance which was required. It will be seen from this how very undesirable it is to have the fields short-circuited.

In Fig. 4 are plotted additional curves with resistance in series with the field circuit, which indicate that for a certain resistance (which is nearly equal to the reactance of the rotor) the maximum loss in the field circuit is obtained. This should also give, from a theoretical point of view, the maximum starting torque. However, it will be seen that this differs very little from that which would be obtained by leaving the field circuit open.

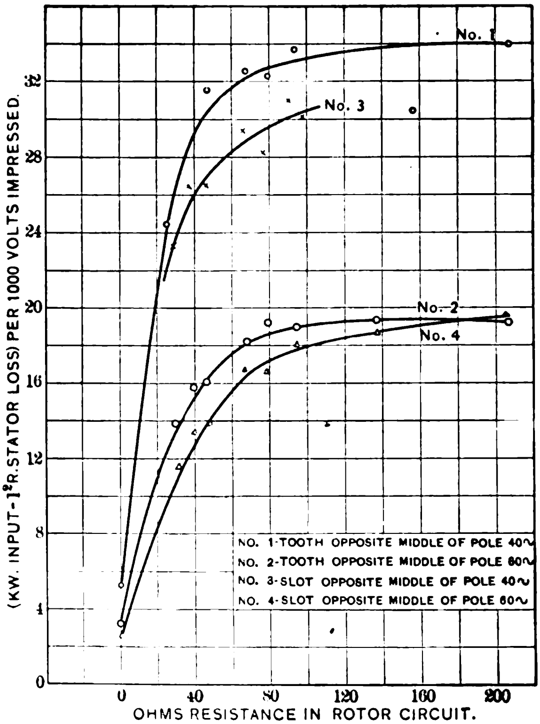

FIG. 3.—VARIATION OF ROTOR INPUT WITH RESISTANCE IN FIELD CIRCUIT Fields Connected Two-Circuit During Tests; No Dampers nor Metal Collars

In Fig. 5 the marked effect of the resistance in the rotor circuit upon the power factor is illustrated and it will be observed how great is the influence of the power factor upon the starting characteristics. On the same curve sheet the stator input in current is shown, which indicates that the current decreases slightly with increased resistance and thus we have obtained for a given impressed electromotive force, not only an increase in torque, but a decrease in stator current as well, by increasing the non-inductive resistance in the rotor circuit.

In order to complete the experiments, tests were also made with copper bars through the heads of the poles and with metal collars between the field coils and the pole heads. The results of these tests are shown in Fig. 6. Even with these circuits the curves show that the extent of the resistance in series with the field winding has a marked effect upon the starting characteristics.

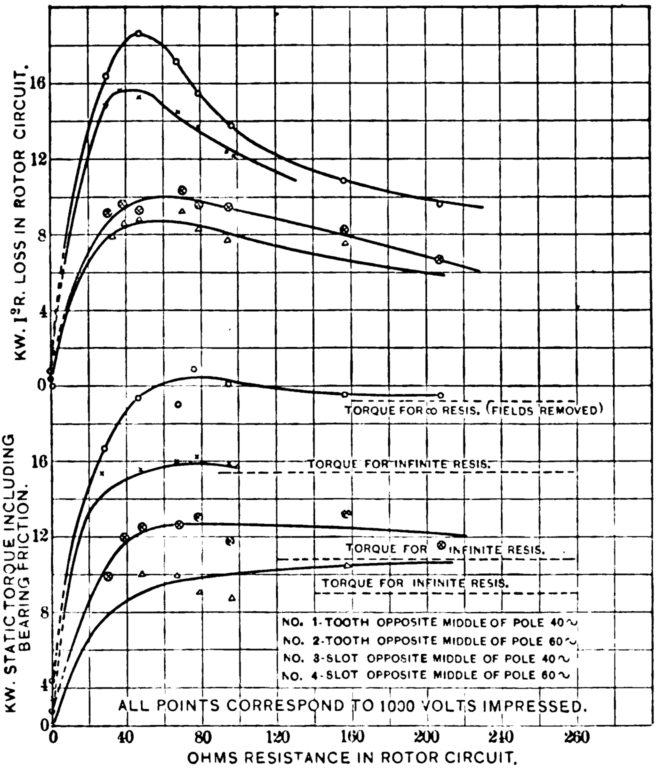

FIG. 4.—VARIATION OF ROTOR $I^2 R$ LOSS AND TORQUE WITH RESISTANCE IN FIELD CIRCUIT
Fields Connected Two-Circuit

The curves in Figs. 1 to 5 inclusive also show clearly the effect of frequency upon the starting characteristics of synchronous motors. They illustrate that, although the torque is greatly increased for a given impressed electromotive force at the lower frequency, this is the result of the increase in mutual flux and the gain in power factor due to the reduction in the counter electromotive force of self-induction, the resistance remaining constant.

MOTORS DURING ACCELERATION

It has often been believed that if a synchronous motor is capable of breaking loose from rest, it will have little difficulty in reaching synchronism. This, however, will depend upon the nature of the load and in order to determine the characteristics of the synchronous motor during acceleration, speed torque curves were taken of a large generator used as a motor, which was provided with laminated poles, amortisseur winding and cast iron field ring. The curves were also taken on a small, high-speed, 60-cycle generator with solid cast steel rotor. In each case the synchronous machine was operated as a motor from a

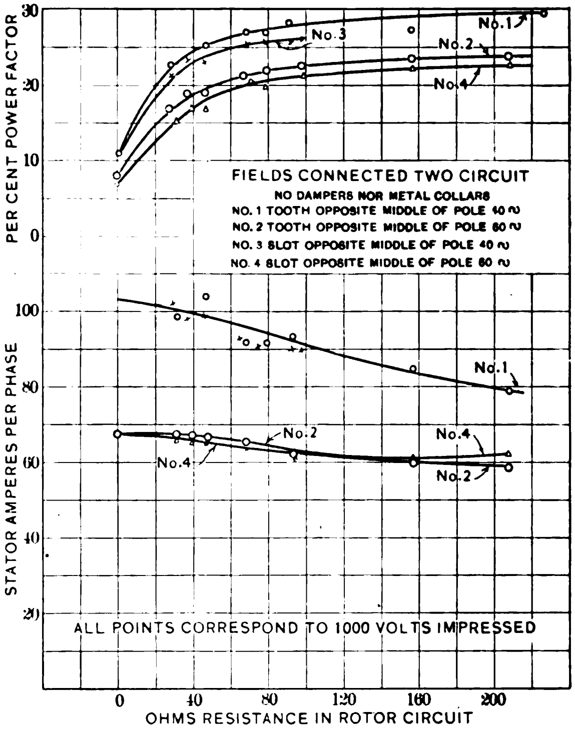

FIG. 5.—VARIATION OF POWER FACTOR AND STATOR CURRENT With Resistance in Field Circuit

three-phase circuit and was belted to a direct current generator, which was loaded by allowing it to force current back into the direct current source of supply. The speed was set by adjusting the field strength of the direct current generator. The electromotive force at the terminals of the stator of the synchronous machine was then raised to as high a value as was

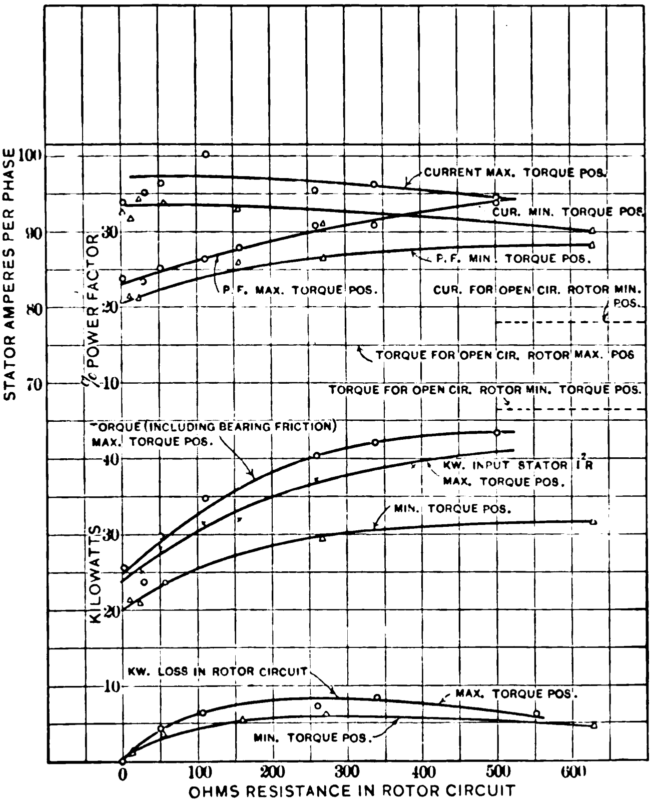

FIG. 6.—VARIATION OF STATOR CURRENT, POWER FACTOR AND KW. With Resistance in Rotor Circuit. Poles Provided with Copper Bars and High-Resistance Metal Collars near Pole Heads.

considered permissible, which in turn caused the synchronous machine to slightly increase in speed, this being finally fixed by the amount of power which it was capable of exerting.

The power input to the synchronous machine was measured by means of wattmeters and the power output of the direct current generator was determined by means of voltmeter and ammeter in the usual way. Loss curves were taken, which enabled us to bring in the losses in the direct current generator, as well as those due to bearing friction and windage in the synchronous machine and allowance was made for the belt loss between the motor and the generator.

Fig. 7 shows the characteristic curves taken on the first synchronous machine with rotor short circuited and with amortisseur winding. Fig. 8 shows the characteristics during acceleration with the amortisseur winding and open circuited fields. Fig. 9 gives the results obtained with amortisseur winding removed and the field circuit opened. These curves indicate the marked effect of the amortisseur winding in producing torque.

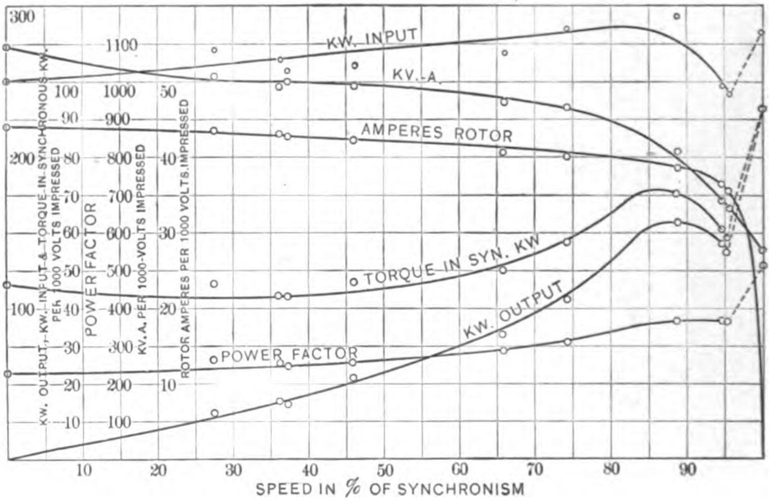

FIG. 7.—CHARACTERISTICS OF SYNCHRONOUS MOTORS DURING ACCELERATION

Fields Short-Circuited with Amortisseur Winding; Laminated Poles; Solid Field Ring

In Fig. 10 are given curves of the solid pole machine without amortisseur winding and with the fields open. All of these curves show how greatly the torque is reduced just before synchronism is reached. In order to increase the torque near synchronism, it was found that the application of a small amount of direct current in the rotor will more definitely define the poles and assist materially in causing the rotor to lock into synchronism. This is greatly dependent upon the excitation applied and for this reason readings were taken on the solid pole machine with direct current in the fields. The direct current is not the total current which flows in the fields, but is that current which flows when no electromotive force is impressed upon the stator. As soon as there is electromotive force induced by transformer action in the field coils, alternating current flows through the exciter armature and is super-imposed upon the direct current which is forced to flow. For example, in one of the curves shown in Fig. 11, the direct current is indicated as 2.85 amperes, whereas the total current in the rotor circuit was approximately 6 amperes.

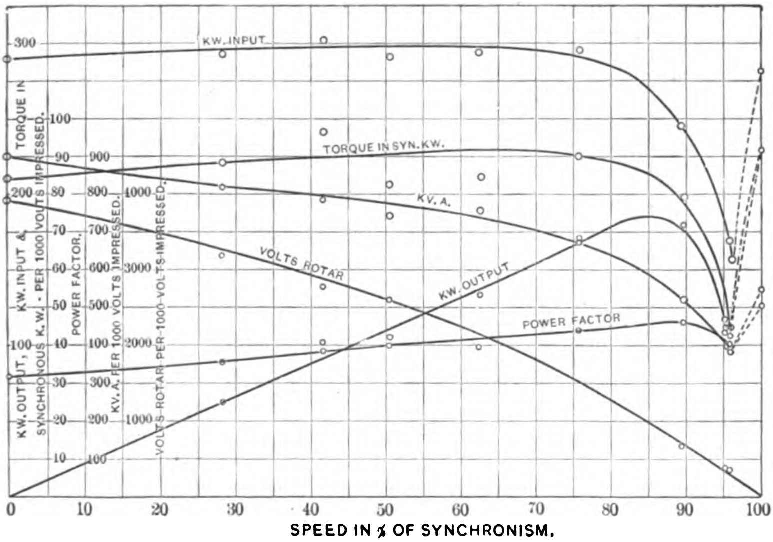

FIG. 8.—CHARACTERISTICS OF SYNCHRONOUS MOTORS DURING ACCELERATION

Open Circuit Fields with Amortisseur Winding; Laminated Poles; Solid Field Ring

In Fig. 12 is given the effect of speed upon the power factor and volt-ampere input with direct current in the fields.

Fig. 13 shows the effect of variation of exciting current upon the torque, kilowatt input and power factor at 90 per cent of synchronism in the same machine.

The writer has not thoroughly investigated the characteristics of synchronous motors near synchronous speed. It would appear, however, from the tests which have been made that the following may be deduced:

1. There is a critical direct current excitation which produces a maximum torque at a definite speed.
2. For best conditions, the exciting current should be increased as the motor accelerates.
3. An increase in exciting current increases the volt-ampere input to the stator.

The writer would explain the phenomenon of dropping off in torque as synchronism is approached as follows:

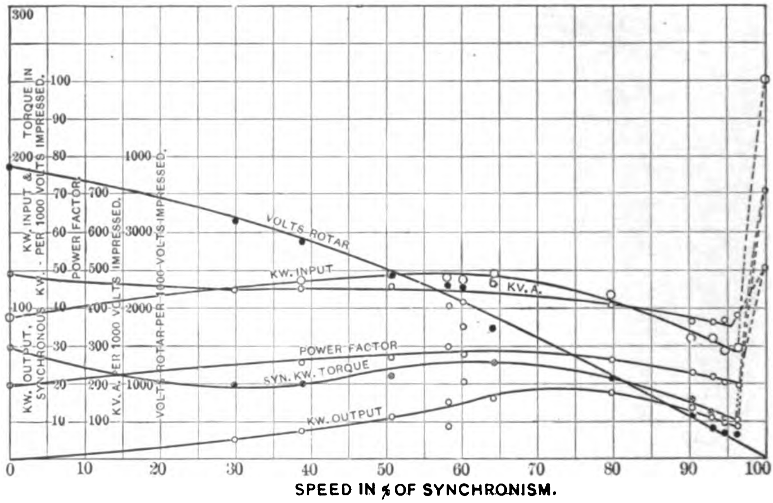

FIG. 9.—CHARACTERISTICS OF SYNCHRONOUS MOTORS DURING ACCELERATION
Open Circuit Fields Without Amortisseur Windings; Laminated Poles; Solid Field Ring

In general, in the synchronous motor at any speed the frequency of the rotor currents is equal to the stator frequency minus the frequency of rotation. As the motor speeds up, the rotor frequency diminishes and the electromotive force induced in the rotor conductors decreases with the corresponding diminution in rotor reactance. Up to about 80 per cent of synchronism the rotor currents are not much affected by the change in frequency, due to the lowering of the reactance with the corresponding reduction in induced electromotive force. As synchronism is neared, however, the influence of the lowering of the rotor frequency becomes more and more noticeable, in that the volt-ampere input drops off considerably and the currents which flow in the rotor circuit are too small to exert much torque. (See Amperes Rotor Curve, Fig. 7.)

When within a few per cent of synchronism, currents in the stator produce magnetomotive forces, which, combined with the hysteresis effect in the rotor itself, tend to prevent the polarity reversing and cause the rotor to lock into synchronism. After the motor has reached synchronous speed, it will run as a synchronous motor, even though there be no excitation in the rotor circuit. The magnetomotive force is then obtained from currents in the stator conductors. Flux is produced by this magnetomotive force and rotates at synchronous speed. Due to the fact that the poles are so clearly defined, the polarity of them remains fixed and the motor continues to operate in synchronism with the generator which supplies it with power and will pull a certain amount of load under these conditions. The effect, then, of exciting the fields with direct current is to more clearly define the poles, preventing the polarity from reversing and assist

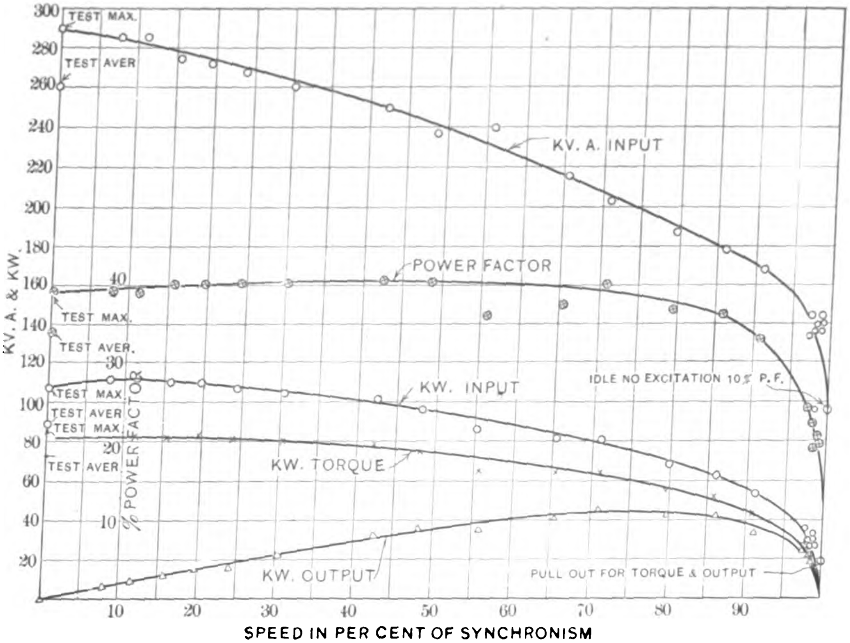

FIG. 10.—CHARACTERISTICS OF SYNCHRONOUS MOTORS DURING ACCELERATION
Solid Poles; Fields Open

materially in causing the rotor to lock into synchronism. The cause of diminution of power factor near synchronous speed is believed to be due to the great amount of exciting current which becomes a very large percentage at this point.

DRIVING OF FANS AND PUMPS

In starting a fan, the power required to drive it increases approximately as the cube of the speed and the torque as the square of the speed. A very small torque is required to start the fan; only sufficient to break it loose from rest and overcome the bearing friction. As it approaches synchronism, however, a large amount of power is required.

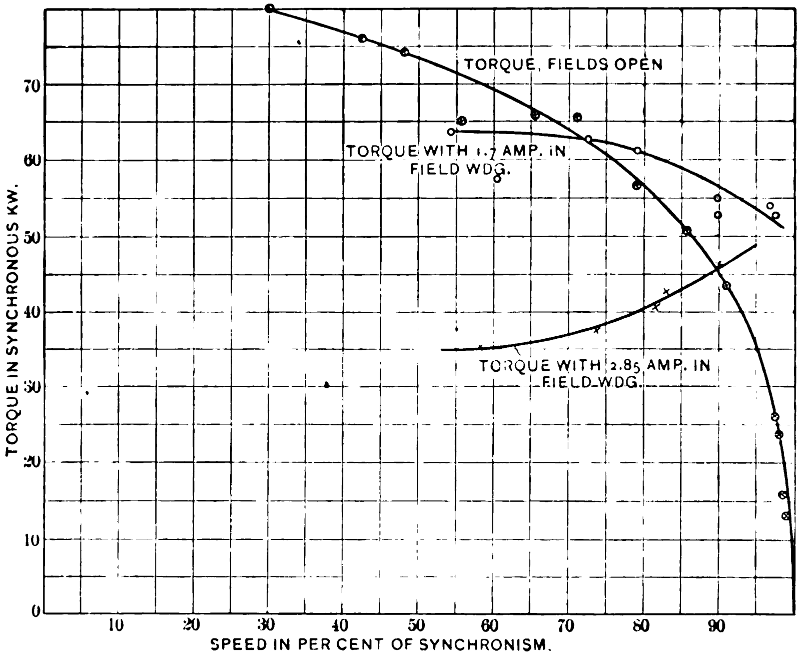

FIG. 11.—SPEED-TORQUE CURVES
With Solid Poles

In the case of a centrifugal pump, it is generally claimed that it is dangerous to start unless the pump is full of water, as otherwise with the small clearances which are needed to obtain high efficiencies, the pump would heat to such an extent as to cause the rotating and stationary members to come into contact and destroy each other. It is also claimed that in order that the pump may begin operating, it should be primed during acceleration.

There is a diversity of opinion among centrifugal pump manufacturers as to the amount of torque which is required to rotate the moving element at synchronous speed with the pump full of water, and the outlet valve closed. The power under such conditions would be absorbed in heating the water, but as this is for a short period it seldom does any harm.

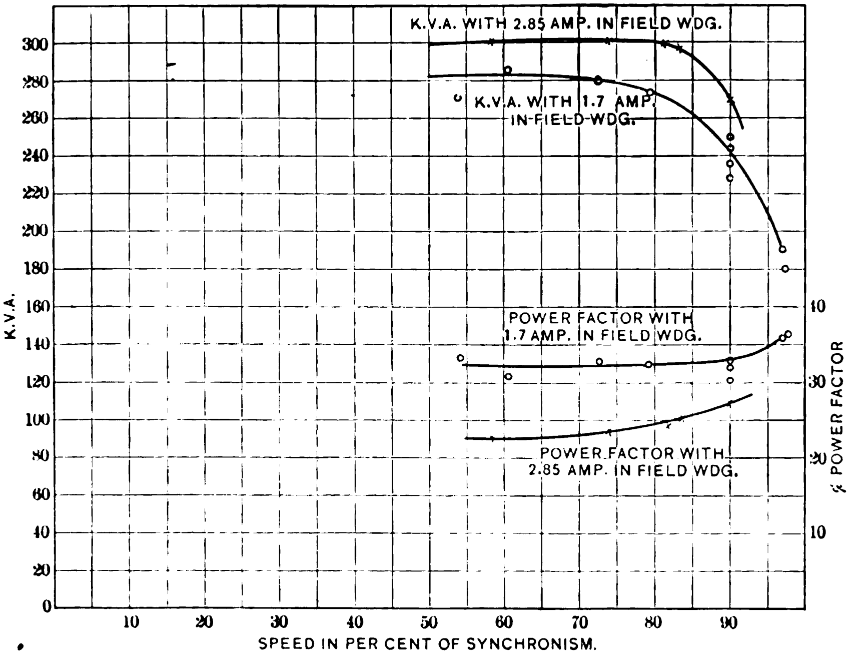

FIG. 12.—EFFECT OF VARYING SPEED ON KV-A. INPUT AND POWER FACTOR
Solid Poles

According to the information which it has been possible for the writer to obtain, this torque varies from 35 per cent to 100 per cent of the torque required to operate the pump under normal conditions. In general a synchronous motor should not be counted upon to exert large torque near synchronism, although if direct current is supplied to the rotor, as described under

"Motors During Acceleration," the torque near synchronism can be considerably augmented. Even so, the motor will pull into synchronism only by drawing a large amount of current from the line and may overheat when it is used to drive a pump or a fan, due to the great quantity of power and current required as synchronism is approached. Sufficient tests have not been made to enable any definite statement to be made in regard to this, and it is believed that a careful investigation of this subject would be productive of fruitful results.

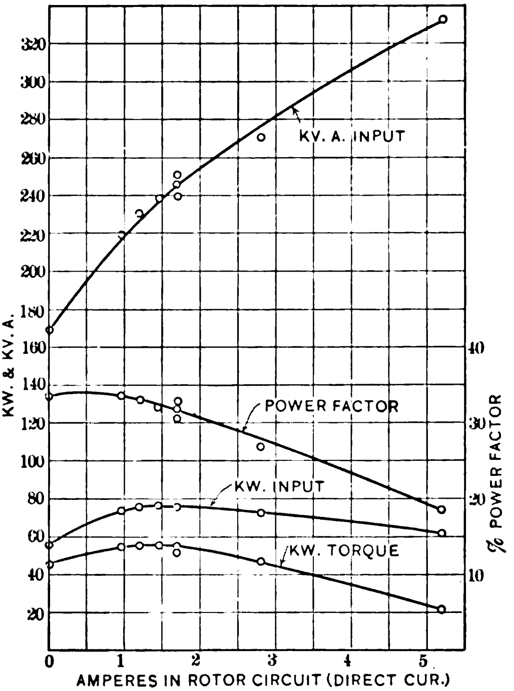

Fig. 13.—Effect of Varying Exciting Current at 90% of Synchronism
Solid Poles

Starting of Motor-Generator Sets

The torque required to start up a motor-generator set can be easily determined by allowing for the static friction in the journals at the instant of starting. From a number of tests which have been made to determine the value of the coefficient of friction when all the oil had been allowed to run out of the journals, it has been found that this factor has a minimum value of 0.2 and seldom exceeds 0.3. Therefore, if we allow 0.3 for the static coefficient of bearing friction, it should be safe in determining the torque required to break the set loose from rest. The following formula will then give the starting torque where μ equals the coefficient of friction, D equals the average shaft diameter in the bearings in inches, W equals the weight in pounds of the complete revolving element, rev. per min. is the revolutions per minute at synchronous speed, and P equals torque expressed in synchronous kilowatts required to start the set.

$$P = \frac{0.746\, \mu\, W\, \pi\, D\ (\text{rev. per min.})}{12 \times 33{,}000} = \frac{\mu\, W D\ (\text{rev. per min.})}{169{,}000}$$

GENERAL LAWS TO BE DEDUCED

For perfectly stable conditions, from the tests which have been made we can usually consider, other things being equal, that the following are approximately correct:

1. The starting torque varies as the square of the impressed voltage.
2. The current varies as the first power of the voltage.*
3. The volt-ampere input varies as the square of the voltage.*
4. The power input varies as the square of the impressed voltage.
5. The power factor is independent of the impressed voltage.
6. The voltage induced in the rotor circuit is proportional to the first power of the impressed voltage.
7. The total loss in the rotor circuit is a reasonably exact measure of the torque developed.

DETERMINATION OF STARTING TORQUE WITH SOLID POLES

The current which flows in the stator of a synchronous motor when a polyphase electromotive force is applied to it, is equal to that voltage divided by the impedance. This impedance, with the motor stationary, consists chiefly of reactance, which appears in both the stator and the rotor. If we were to measure the reactance of the stator with the rotor out, using a single-phase current applied between neutral and terminal, in the case of a three-phase machine, and applied to one of the phases in the case of a two-phase machine, we would find that with the rotor in, the current which flows bears a nearly definite relation to the electromotive force divided by the reactance which is measured with the rotor removed. Hence this at once gives us the means for determining from experiment what the kilovolt ampere input will be with the rotor stationary, provided we know the stator reactance.

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*Due to saturation of the paths of leakage flux, as well as to increase in resistance with temperature, the current does not necessarily vary as the first power of the voltage. The effect of saturation of leakage paths is especially noticeable with solid poles.

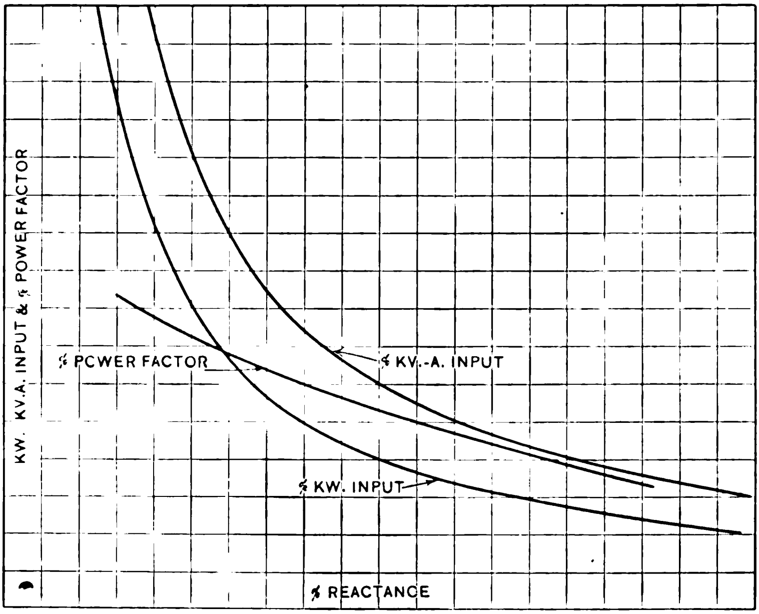

FIG. 14.—KW., KV-A. INPUT AND POWER FACTOR AS A FUNCTION OF REACTANCE

In Fig. 14 is shown the forms of the curves obtained by plotting the kilovolt ampere input against percentage reactance for solid pole machines. It will be seen that if the reactance is doubled, the kilovolt ampere input is reduced to one-half. In other words, it has been found that this curve approximates an equilateral hyperbola.

It is not exactly correct to plot the power factor of the incoming current against the percentage reactance, since, if the rating of the machine were changed, the percentage reactance would be correspondingly altered while the power factor would not be affected. Nevertheless, the machines from which the points for power factor were plotted were designed on similar lines and they gave a reasonably smooth curve. It is evident that the power input to the stator is the power factor multiplied by the volt-ampere input, so that we obtain the power input curve by multiplying the ordinates of the other two curves. This gives us a very rapid and quite accurate means of predicting the current and power which is taken in by a synchronous motor at the instant of starting, if we know the reactance. The starting torque is then obtained directly by deducting the losses in the stator from the power input.

These curves are plotted from tests made on two and three-phase, 25 and 60 cycle motors with solid steel poles. It appears that for a given percentage reactance, the difference in number of phases and in frequency has little influence.

These curves are intended to apply to the input with normal voltage impressed upon the stator. If this voltage is reduced by means of an auto-transformer, the power and volt-ampere input are reduced in proportion to the square of the voltage, whereas the power factor remains the same.

These curves have been obtained from machines in which the field circuit was opened at the instant of starting.

In order to predict the reactance of the stator, a formula for this has been derived which appears in the appendix and is repeated here as follows:

$$X_s = \frac{7.9 \sim p\, a^2 S\, \lambda_s}{10^8} \left\{ \left(1 - \frac{3}{4}\, \frac{\beta n}{180^\circ}\right) \left[\frac{d_1}{3 W_s} + \frac{d_2}{W_s} + \frac{2 d_3}{W_s + b_s} + \frac{d_4}{b_s} + \log_{10}\left(1 + \frac{\pi\, W_t}{W_s}\right) + 2 \log_{10}\left(1 + \frac{\pi\, W_t}{2\, W_s + W_t}\right) \right] + 0.4\, s\, \phi_f \left(\frac{M.T.}{\lambda_s} - 2\right) \right\} \qquad (1)$$

For the meaning of the symbols given in this equation, see notation.

DETERMINATION OF STARTING CHARACTERISTICS WITH LAMINATED POLES AND AMORTISSEUR WINDING

The losses which appear in the stationary rotor of a synchronous motor when the field circuit is open and polyphase electromotive forces are applied to the stator are:

1. Losses due to eddy currents in field ring, end plates, rivets, etc.
2. Losses in the rotor bars.
3. Losses in the end rings of the amortisseur winding.
4. Losses due to circulating currents in the metal collars surrounding the poles near the heads, if collars are used.
5. Losses due to currents in the short-circuited end turns of the field coils.
6. Losses due to contact resistance.
7. Losses due to a pulsating component of flux, not productive of torque.

In the following treatment the first three of these only are considered. To bring into the equations the losses due to circulating currents in the collars would cause them to be very involved, and as most synchronous motors with amortisseur windings do not have collars on the rotors, it was deemed best to omit the effect of current in them upon the starting characteristics.

The losses due to currents in the end turns of the field coils are comparable with those in the collars. These losses may reach such magnitude as to cause great local heating, especially if the field coils are made of wire. It is best, therefore, to avoid short-circuiting the end-turns, and to hold them securely by some other means. As far as the detrimental effects upon the starting characteristics are concerned, however, it should be borne in mind that with but one turn at each end of the coil short-circuited upon itself, the magnitude of its resistance is comparable with that of its reactance, whereas this does not hold with the entire coil short-circuited, as the resistance is proportional to the first power, and the reactance to the square, of the number of turns.

The losses due to contact resistance are discussed under "Notes on Determination of Starting Characteristics with Laminated Poles."

The losses in the rotor which are not productive of torque are very difficult to compute. For further discussion of this, see "Unbalance in Phases," and "Star and Delta Connections."

Of the first three losses enumerated above, those due to eddy currents are discussed under "Notes on Determination of Starting Characteristics with Laminated Poles." The writer has had the opportunity to investigate one case only and found this loss to be about 30 per cent of the total rotor loss.

It is first necessary to know how much starting torque is required, and this should include the torque required to overcome the static bearing friction of the motor. All torques and losses should be expressed in synchronous watts (or simply watts). From this total loss, the eddy current loss Pe should be deducted. This then leaves the losses in the bars Pb and end rings. $P.e.r.$

NOTATION

a = number of active conductors per slot = number of conductors per slot divided by number of parallel circuits in armature.

$A.T.$ = ampere turns per pole required to force flux ϕ through magnetic circuit of one pole.

b = number of rotor bars per pole.

b_s = opening at top of slot (for stator or rotor as case may be).

C = Carter fringing co-efficient from curve. Fig. 19.

d_1 = total depth of conductor in slot (for stator or rotor as case may be).

d_2 = depth of slot between top of conductor and top of parallel sides.

d_3 = depth of variable width portion of slot (for partly closed slot only).

d_4 = depth of parallel sides of slot opening, (for partly closed slot only).

$D_{e.r.}$ = average diameter of end ring.

E = impressed electromotive force per phase or per leg if star connected.

E_1 = stator equivalent of electromotive force consumed by rotor bar and end ring resistance.

E_2 = stator equivalent of electromotive force consumed by rotor bar and end ring reactance.

E_3 = stator equivalent of electromotive force consumed by rotor impedance.

E_4 = electromotive force consumed by stator reactance.

E_5 = electromotive force consumed by stator resistance.

E_r = electromotive force induced in field coils.

E_{r_1} = electromotive force consumed by rotor bar and end ring resistance.

E_{r_2} = electromotive force consumed by rotor bar and end ring reactance.

F_b = sectional area of one rotor bar.

$Fe.r.$ = sectional area of end ring.

F_s = sectional area of one stator conductor.

h = linear distance between adjacent rotor bars in same pole.

I = effective value of stator current per phase.

I_b = r.m.s. value of current per rotor bar.

I_0 = magnetizing current per phase corresponding to $A.T.$

I_1 = stator equivalent, in amperes per phase, of current in rotor bars.

$j = \sqrt{-1}$.

k = distribution factor = ratio of vector to algebraic sum of electromotive forces in stator conductors in one phase or leg.

K = constant for computing losses in end rings

L, L_1 etc. = inductances.

m = ratio of vector to arithmetical sum of currents in rotor bars in one-half pole.

M = short pitch factor for use with reactance $= \frac{5}{8}$ for three phase and $\frac{3}{4}$ for two phase and single phase.

$M.T.$ = mean turn of stator coil.

n = number of phases.

N = number of turns per coil in fields.

N_1 = total number of stator slots.

p = number of poles.

p_f = short pitch factor = decrease in electromotive force due to fractional pitch $= \cos\frac{\beta}{2}$

P_b = watts lost by resistance of rotor bars.

Pe = watts lost by eddy current in field ring and other solid portions.

$Pe.r.$ = watts lost by resistance of end rings.

R_b = resistance of one rotor bar.

R_s = resistance of one phase of stator winding.

S = number of stator slots per pole per phase.

t = ratio of transformation of voltage.

u = polar arc.

w_b = weight per unit volume of material in rotor bars.

$w_{e.r.}$ = weight per unit volume of material in end rings.

Wb = watts per unit weight in rotor bars.

$We.r.$ = watts per unit weight in end rings.

W_s = width of main portion of rectangular slot for stator or rotor as case may be.

W_t = width of stator tooth at inner periphery of stator.

X_b = reactance of one rotor bar.

X_f = stator end connection reactance.

X_s = reactance per leg of stator.

X_{s_1} = stator slot reactance.

X_t = tooth tip reactance.

X_z = zigzag reactance.

α = angle of lag of eddy currents in rotor behind electromotive force induced in rotor bars.

β = electrical angle that coils are dropped back of full pitch.

γ = angle between stator equivalent of rotor bar current I_1 and total current I.

δ = angle between stator current I and stator equivalent of rotor impedance electromotive force (E_3).

Δ = radial length of air gap.

θ = angle of lag of total stator current behind the impressed electromotive force = angle whose cosine is power factor.

λ = average slot pitch.

λ_b = axial effective length of rotor bar in pole only.

λ_b' = axial effective length of rotor bar between end rings.

λ_s = axial gross length of stator iron.

ρ_b = resistance of unit cube of material in rotor bars.

$\rho_{e.r.}$ = resistance of unit cube of material in end rings.

ρ_s = resistance of unit cube of material in stator coils.

σ = field ring leakage factor = ratio of mutual flux linking with rotor bars to mutual flux entering field ring.

σ' = field coil leakage factor = ratio of mutual flux linking with rotor bars to average mutual flux linking with field coils.

τ = pole pitch, at average end ring diameter.

τ' = pole pitch, at inner periphery of stator.

ϕ = useful (or mutual) flux per pole linking with rotor bars.

ϕ_f = leakage lines per ampere per unit length of end connections from Fig. 18.

ψ = angle of lag of current in rotor bars behind electromotive force induced therein.

ω = electrical angle between adjacent rotor bars in same pole. In appendix ω = electrical angle between currents in adjacent phases.

$\sim$ = frequency, cycles per second.

DERIVATION OF FORMULAE FOR AMORTISSEUR WINDING AND LAMINATED POLES

The leakage reactance of each rotor slot, if round slots are used is:

$$X_b = \frac{2\pi \sim \lambda_b{}^{*}\, 0.4\,\pi}{10^8}\left(0.545 + \frac{d_4}{b_s}\right) \tag{2}$$

If the slots are rectangular in section,

$$X_b = \frac{2\pi \sim \lambda_b{}^{*}\, 0.4\,\pi}{10^8}\left(\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{W_s + b_s} + \frac{d_4}{b_s}\right) \tag{3}$$

For the leakage of the end ring see " Notes on Determination of Starting Characteristics with Laminated Poles."

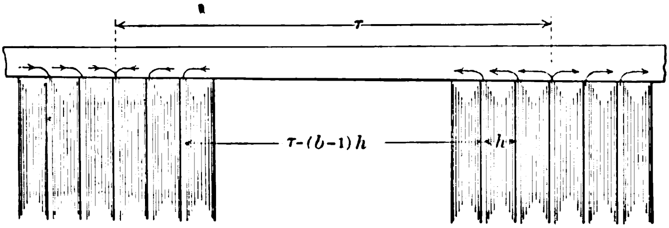

FIG. 15

The resistance of each rotor bar is:

$$R_b = \frac{\rho_b\,\lambda_b'}{F_b} \tag{4}$$

The losses in the bars are given by:

$$P_b = I_b{}^2\,R_b\,p\,b \tag{5}$$

$$P_b = I_b{}^2\,p\,\frac{b\,\rho_b\,\lambda_b'}{F_b} \tag{6}$$

In order to calculate the losses in the end rings we shall break the rings into two portions: those portions of the rings between the first and last bars of the same poles and those portions between the nearest bars of adjacent poles. If all the currents are in phase with one another, the former of these losses is:

---

*If inches are used throughout, substitute 3.19 for 0.4 π. The derivation of the equation for the round slot will be found in the appendix. The other equation for rectangular slot is well known.

$$(Pe.r.)_1 = 4\,p\,\frac{\rho_{e.r.}}{Fe.r.}\,I_b^2\,h\,K \tag{7}$$

where K is a constant depending upon the number of bars per pole (b). See Fig. 15. If there are but two bars per pole, there is no current in the rings between the bars except that due to phase difference between the electromotive forces induced in the bars which for the present we shall neglect. If the number of bars per pole be three, then the current from the middle bar we assume to divide equally, one-half flowing in each direction. Calculating from the center of the poles and in one ring only, the loss between bars with three bars per pole is proportional to

$$\left(\frac{I_b}{2}\right)^2 = 0.25\,I_b^2. \text{ See Fig. 15.}$$

Similarly for $b = 4$, the losses are proportional to $(1\,I_b)^2 = I_b^2$. For five bars per pole, we have

$$\left(\frac{I_b}{2}\right)^2 + \left(\frac{3\,I_b}{2}\right)^2 = 2.5\,I_b^2 \text{ etc.}$$

The following series has been found to hold for any value of b.

$$K = \left(\frac{b}{2} - 1\right)^2 + \left(\frac{b}{2} - 2\right)^2 + \left(\frac{b}{2} - 3\right)^2 + \left(\frac{b}{2} - 4\right)^2 + \dots$$
$$\left(\frac{b}{2} - \frac{b}{2}\right)^2 \text{ for } b = \text{even.} \tag{8}$$

and

$$K = \left(\frac{b}{2} - 1\right)^2 + \left(\frac{b}{2} - 2\right)^2 + \left(\frac{b}{2} - 3\right)^2 + \left(\frac{b}{2} - 4\right)^2 + \dots$$
$$\left[\frac{b}{2} - \left(\frac{b}{2} - \frac{1}{2}\right)\right]^2 \text{ for } b = \text{odd.} \tag{9}$$

Or, tabulating, we obtain:

NUMBER OF BARS PER POLE	K
2	0
3	.25
4	1.00
5	2.50
6	5.00
7	8.75
8	14.00
9	21.00
10	30.00

Equation (7) is only approximately correct as the assumption is made that the currents in the several bars are in phase with each other, so that the vector sum would be less than the arithmetical sum. This discrepancy is offset, however, by the fact that no account is taken of the losses in the rings due to circulating currents between bars in the same pole resulting from a difference in phase between the currents in them.

The loss in the rings between the nearest bars of adjacent poles is given by:

$$(Pe.r.)_2 = [\tau - (b - 1)\, h]\, 2\, p\, \frac{\rho_{e.r.}}{Fe.r.}\, I_{er}^2 \qquad (10)$$

But

$$Ie.r. = \frac{b\, I_b}{2}\, m \qquad (11)$$

where *m* is the ratio of the vector sum to the arithmetical sum of currents in bars in one-half of each pole. The following table gives values of "*m*".

Number of bars per pole	"*m*"
2	1
3	$\frac{1}{1.5}\sqrt{1.25 + \cos\omega}$
4	$\cos\frac{\omega}{2}$
5	$\frac{1}{2.5}\sqrt{2.25 + 3\cos\omega + \cos 2\omega}$
6	$\frac{1 + 2\cos\omega}{3}$
7	$\frac{1}{3.5}\sqrt{3.25 + 5\cos\omega + 3\cos 2\omega + \cos 3\omega}$
8	$\frac{1}{2}\left(\cos\frac{\omega}{2} + \cos\frac{3\omega}{2}\right)$
9	$\frac{1}{4.5}\sqrt{4.25 + 7\cos\omega + 5\cos 2\omega + 3\cos 3\omega + \cos 4\omega}$
10	$\frac{1 + 2\cos\omega + 2\cos 2\omega}{5}$

In the above "ω" is the electrical angle between adjacent bars in the same pole.

Then

$$(Pe.r.)_2 = [\tau - (b - 1)\, h]\, p\, \frac{\rho_{e.r.}}{Fe.r.}\, \frac{b^2 I_b^2 m^2}{2} \qquad (12)$$

Combining equations (**7**) and (**12**) we have

$$Pe.r. = (Pe.r.)_1 + (Pe.r.)_2 = p\,\frac{\rho_{e.r.}}{Fe.r.}\,I_b^2 \left\{ 4h\,K + \frac{[\tau - (b-1)\,h]\,b^2\,m^2}{2} \right\} \qquad \textbf{(13)}$$

and the total loss in the bars and rings is

$$Pe.r. + P_b = p\,\frac{\rho_{e.r}}{Fe.r.}\,I_b^2 \left\{ 4\,h\,K + \frac{[\tau - (b-1)\,h]\,b^2\,m^2}{2} \right\} + p\,b\,I_b^2\,R_b \qquad \textbf{(14)}$$

The current per bar is then

$$I_b = \sqrt{\frac{Pe.r. + P_b}{p\left\{ b\,R_b + \frac{\rho_{e.r.}}{Fe.r.}\left[4\,h\,K + \frac{\{\tau-(b-1)\;h\}\;b^2\;m^2}{2}\right]\right\}}} \qquad \textbf{(15)}$$

The above equation enables one to determine the current per bar if the proportions in the amortisseur winding are known. If we are to decide upon them, however, we may use the following method:

We may allow a certain number of watts per unit weight of material in the rings and bars, these being fixed by the permissible temperature rise of these parts at starting and the duration of the starting period. With this in view, we have:

Weight bars $= w_b\,b\,F_b\,\lambda_b'\,p$ **(16)**

Weight rings $= 2w_{e.r.}\,\pi\,De.r.\,Fe.r.$ **(17)**

Loss per unit weight in bars =

$$\frac{I_b^2\,p\,b\,\rho_b\,\lambda_b'}{w_b\,b\,F_b^2\,\lambda_b'\,p} = \frac{I_b^2\,\rho_b}{w_b\,F_b^2} = W_b \qquad \textbf{(18)}$$

Loss per unit weight in rings =

$$\frac{p\;\rho_{e.r.}\,I_b^2\left\{4\,h\,K + \frac{[\tau-(b-1)\;h]\,b^2\,m^2}{2}\right\}}{2\,w_{e.r.}\,\pi\,D\,e.r.\;F^2e.r.} = We.r. \qquad \textbf{(19)}$$

Solving these equations for F_b and $Fe.r.$, we obtain:

$$F_b = I_b\sqrt{\frac{\rho_b}{w_b\,W_b}} \qquad \textbf{(20)}$$

$$Fe.r. = I_b\sqrt{\frac{p\ \rho_{e.r.}\ \}4\,h\,K + \frac{1}{2}\,[\tau - (b-1)\,h]\,b^2\,m^2}{2\,w_{e.r.}\,\pi\,De.r.\,We.r.}} \tag{21}$$

Substituting these values for F_b and $Fe.r.$ and the value of R_b from equation (**4**) in equation (**14**), we obtain, after simplifying

$$Pe.r. + P_b = I_b[\sqrt{p\,\rho_{e.r.}\ \}4\,hK + \frac{1}{2}[\tau-(b-1)h]\,b^2m^2\{\,2w_{e.r.}\pi\,De.r.\,We.r.} + p\,b\,\lambda_b'\sqrt{w_b\,W_b\,\rho_b} \tag{22}$$

and I_b =

$$\frac{Pe.r. + P_b}{\sqrt{p\,\rho_{e.r.}\ \}4\,hK + \frac{1}{2}[\tau-(b-1)h]b^2\,m^2\{\,6.28w_{e.r.}\,De.r.\,We.r.} + p\,b\,\lambda_b'\sqrt{w_b W_b \rho_b}} \tag{23}$$

This last equation enables us to determine at once the current per bar without knowing their sections. These may be found by substituting in equations (**20**) and (**21**) after finding I_b.

The ohmic drop in each bar is $= I_b\,R_b$ (**24**)

and

$$\frac{Pe.r. + P_b}{P_b} = \frac{E_{r_1}}{I_b\,R_b} \tag{25}$$

hence

$$E_{r1} = \frac{I_b\,R_b\,(Pe.r. + P_b)}{p\,R_b\,b\,I_b^2} = \frac{Pe.r. + P_b}{p\,b\,I_b} \tag{26}$$

Taking the ratio of transformation of voltages to be the voltage per leg in the stator corresponding to the voltage in one bar in the rotor, we have:

$$t = a\,S\,k\,p_f\,p \tag{27}$$

and $E_1 = t\,E_{r1}$ (**28**)

$$E_2 = t\,E_{r2} = t\,X_b\,I_b \tag{29}$$

$$E_3 = \sqrt{E_1^2 + E_2^2} \tag{30}$$

In equation (**29**) X_b should be increased above rotor bar reactance so as to include end ring reactance if this latter be of sufficient magnitude.

A better understanding of the manner in which the losses due to eddy currents *Pe* are brought in, may be obtained by referring to Fig. 16. This illustrates for simplicity, a hedgehog transformer with a large amount of leakage. The primary winding *A* corresponds to the stator winding of the synchronous motor;

the secondary winding B corresponds to the amortisseur winding of the synchronous motor; and the secondary winding C corresponds to the eddy current paths in the field ring, rivets, etc. The electromotive force per turn induced in C is smaller than that induced in B and also smaller than the counter electromotive force induced in A. Nevertheless all three electromotive forces are in time phase with one another. A certain portion of the main primary flux ϕ_1 links with all turns; a second portion ϕ_2 links with A and B but not with C; and a third portion ϕ_3 links only with A. Similarly there are leakage fluxes (ϕ_4, ϕ_5 and ϕ_6) due to secondary currents which link only with the secondary and not with the primary circuits. We have seen that the equivalent electromotive force induced in B (the amortisseur winding) is given by E_3. The equivalent electromotive force induced in the solid portions (in stator terms) is $\frac{E_3}{\sigma}$ where σ is the leakage factor representing the leakage flux between poles. The value of the various eddy currents equals their electromotive forces divided by their impedances, and lag behind their pressures by an angle whose tangent is their reactance divided by their resistance $\left(\text{or } \alpha = \tan^{-1} \frac{X}{R}\right)$ Hence, if I_2 is the equivalent stator current of the summation of eddy currents, we have:

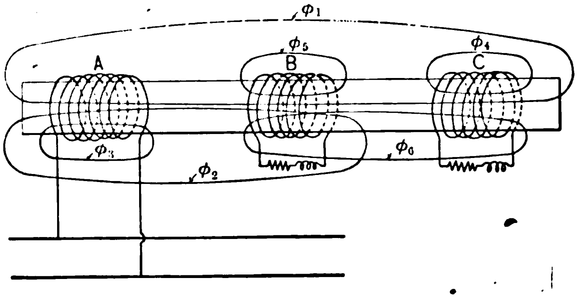

FIG. 16

$$Pe = \frac{n\,E_3}{\sigma} I_2 \cos\alpha \tag{31}$$

$$\text{or } I_2 = \frac{Pe\,\sigma}{n\,E_3 \cos\alpha} \tag{32}$$

For the determination of *Pe*, σ and cos α see "Notes on Determination of Starting Characteristics with Laminated Poles."

The stator equivalent of the rotor bar current is:

$$I_1 = \frac{b\, I_b}{n\, a\, S} \tag{33}$$

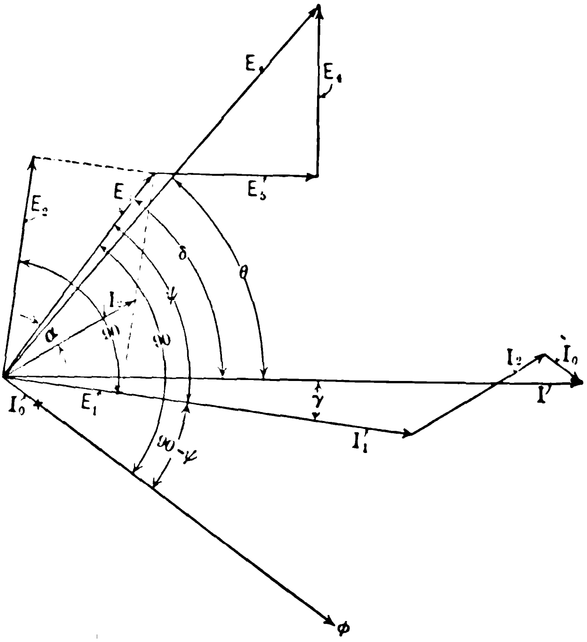

Fig. 17

And the magnetizing current is

$$I_0 = \frac{A.T.}{\frac{\sqrt{2}}{2 \times 2}\, n\, a\, s} = \frac{2\sqrt{2}\, A.T.^*}{n\, a\, s} \tag{34}$$

In this equation *A.T.* can be computed in the ordinary way for determining the ampere turns required to force flux corresponding to E_3 across the single air gap. The voltage induced in the field coils is

$$E_r = \frac{4.44\, \phi\, N\, p \sim}{10^8\, \sigma'} \tag{35}$$

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*This equation, while slightly in error, is the same as is used frequently for computing the armature reaction. It appears, among other works, in Berg's *Electrical Energy.*

and since

$$E_3 = \frac{2.22\,\phi\,a\,S\,k\,p_f\,p\sim}{10^8} = \frac{2.22}{10^8}\,\phi\,t\sim \qquad \textbf{(36)}$$

(See equation (**27**) for value of t).

$$Er = \frac{2\,N\,p}{\sigma'\,t}\,E_3 \qquad \textbf{(37)}$$

The resistance per lag of the stator is

$$R_s = \frac{\rho_s\,(M.T.)a\,s\,p}{2\,F_s} \qquad \textbf{(38)}$$

And the leakage reactance is:

$$X_s = \frac{7.9^{\dagger}\sim p\,a^2\,S\,\lambda_s}{10^8}\left\{\left(1-\frac{M^{\S}\,\beta\,n}{180^\circ}\right)\left(\frac{d_1}{3\,W_s}+\frac{d_2}{W_s}+\frac{2\,d_3}{b_s+W_s}+\right.\right.$$

$$\frac{d_4}{b_s}+\frac{0.425\,u\,(W_t+CW_s)^2}{\tau'\,\triangle\,\lambda}+\left(1-\frac{u}{\tau'}\right)\left[\log_{10}\left(1+\frac{\pi\,W_t}{W_s}\right)+\right.$$

$$\left.\left.\left.2\log_{10}\left(1+\frac{\pi\,W_t}{2\,W_s+W_t}\right)\right]\right)+0.4\,S\,\phi_f\left(\frac{M.\,T.}{\lambda_s}-2\right)\right\} \qquad \textbf{(39)}$$

It will be seen that

$$E_5 = R_s\,I \qquad \textbf{(40)}$$

and

$$E_4 = X_s\,I \qquad \textbf{(41)}$$

We are now prepared to combine the various quantities for the determination of the electromotive force current and power supplied to the motor. Counter-clockwise rotation of *vectors* will be considered positive. See Fig. 17.

[†] If inch system be used, this should be 20. instead of 7.9.

[§] $M = \frac{5}{8}$ for six-phase winding connected for three phase; and is $\frac{3}{4}$ for four-phase winding connected for two-phase. β = angle dropped back from full pitch: for example, if there be 12 slots per pole, and pitch of slot 1 to slot 11, $\beta = \frac{2 \times 180^\circ}{12} = 30^\circ$. For derivation see appendix.

Take I_1 as zero vector. In phase with I_1 is the stator equivalent of the rotor bar resistance drop, E_1. Leading I_1 by 90 degrees is the stator equivalent of the rotor bar reactance drop E_2, which combined with E_1 gives E_3. Lagging behind E_3 by 90 degrees (that is, leading the induced secondary voltage by 90 degrees) is the flux ϕ. In phase with ϕ is the magnetizing current I_0. Lagging behind E_3 by angle α is I_2. The angle which E_3 makes with I_1 is ψ. That is:

$$\psi = \tan^{-1} \frac{E_2}{E_1} \tag{42}$$

The angle between I_2 and I_1 is $(\psi - \alpha)$, and

$$\underset{\cdot}{I_2} = I_2 \cos (\psi - \alpha) + j\, I_2 \sin (\psi - \alpha) \tag{43}$$

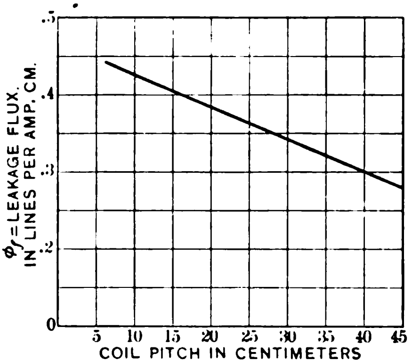

Fig. 18.—End Connection Leakage

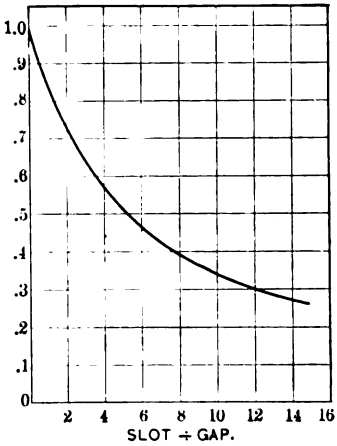

Fig. 19.—"Carter" Fringing Coefficient

The angle between I_0 and I_1 is $(90° - \psi)$ so that

$$\underset{\cdot}{I_0} = I_0 \cos (90° - \psi) - j\, I_0 \sin (90° - \psi) = I_0 \sin \psi - j\, I_0 \cos \psi \tag{44}$$

The total stator current taken vectorially is

$$\underset{\cdot}{I} = \underset{\cdot}{I_1} + \underset{\cdot}{I_2} + \underset{\cdot}{I_0} \tag{45}$$

$$\underset{\cdot}{I} = [I_1 + I_2 \cos (\psi - \alpha) + I_0 \sin \psi] + j\, [I_2 \sin (\psi - \alpha) - I_0 \cos \psi] \tag{46}$$

or

$$I = \sqrt{(I_1 + I_2 \cos (\psi - \alpha) + I_0 \sin \psi)^2 + (I_2 \sin (\psi - \alpha) - I_0 \cos \psi)^2} \tag{47}$$

The angle between I and I_1 is given by

$$\gamma = \tan^{-1} \frac{I_2 \sin(\psi - \alpha) - I_0 \cos \psi}{I_1 + I_2 \cos(\psi - \alpha) + I_0 \sin \psi} \tag{48}$$

Knowing γ we may find

$$\delta = \psi - \gamma \tag{49}$$

Taking I as zero vector, we have

$$\dot{E}_3 = E_3 \cos \delta + j\, E_3 \sin \delta \tag{50}$$

In phase with I is the stator resistance drop $E_5 = R_s\, I$ and leading I by 90 degrees is the stator inductive drop $X_s\, I$. Combining E_3, E_5 and E_4 we obtain the impressed voltage per phase:

$$\dot{E} = \dot{E}_3 + \dot{E}_5 + \dot{E}_4 = E_3 \cos \delta + E_5 + j\, E_3 \sin \delta + E_4 \tag{51}$$

or

$$E = \sqrt{(E_3 \cos \delta + E_5)^2 + (E_3 \sin \delta + E_4)^2} \tag{52}$$

The power factor at the stator terminals is

$$P.F. = \cos\, \theta = \cos\, \tan^{-1} \frac{E_3 \sin \delta + E_4}{E_3 \cos \delta + E_5} \tag{53}$$

The kilovolt ampere input is

$$KV\text{-}A. = \frac{n\, E\, I}{1000} \tag{54}$$

The kilowatts input is

$$KW. = \frac{n\, E\, I \cos \theta}{1000} \tag{55}$$

NOTES ON DETERMINATION OF STARTING CHARACTERISTICS WITH LAMINATED POLES

While the theory given above covers a more or less ideal case, the engineer using such equations should bear in mind that actual conditions must always be different from those of computation. For example, the assumption is made that the frequency of the currents in the rotor is the same as the line frequency. Undoubtedly the departure from a sinusoidal distribution of flux will cause the wave form of currents induced to depart considerably from that of a sine wave and there are introduced frequencies other than the fundamental. No tests have been made to determine this wave form, although undoubtedly the volts consumed by reactance must be greatly influenced by the value of this frequency.

Another source of error is the effect of the contact resistance between the bars and the rings, which may be a large percentage of the total resistance of the rotor circuit. It is quite conceivable to have bars in large machines carrying 5000 amperes in which the drop at a poorly made contact would be a considerable percentage of the total with this amount of current. To insure against having the large contact resistance, it might be advisable to solder the joint. However, due to the difficulties which would appear in case the rings were to be removed, this would scarcely be a satisfactory solution. Therefore the engineer should allow for this discrepancy in the same way that he would allow in induction motors for contact resistance between the rings and the rotor bars when they are bolted together. Fortunately, however, this contact resistance is in favor of obtaining a smaller current input for the same starting torque.

In case the construction is such as to permit of the bars passing through slots which are entirely closed at the tops, tests should be made to determine the reactance for different currents with this type of slot. If these bridges over the tops of the slots were in laminated portions, the value of the reactance would be considerably different than if the metal were solid, due to the fact that eddy currents would be produced in the latter, which would tend to reduce the reactance. It would be very difficult to compute the reactance of this part of the circuit by theoretical means.

If the poles be laminated and the field ring solid, the losses in the field ring could be determined experimentally by taking careful readings with and without the amortisseur winding on the rotor. The voltage induced in the field coils is a crude measure of the flux which enters the solid field ring. As the losses due to eddy currents in the solid field ring are dependent upon the flux which enters it, these losses would be the same for the same voltages induced in the field coils with and without the amortisseur winding. By observing for a definite voltage induced in the field coils, the starting torque as well as the power input to the stator (from which latter the stator losses may be deducted) the fraction of the total rotor loss which appears in the solid portions can be experimentally determined. From these tests the proportions of rotor losses in other machines could be predicted.

It is important to know the percentage of the leakage flux from pole to pole, or the equivalent, the difference between the flux which enters the head of the pole and that which enters the field ring. This can be determined experimentally by noting the voltage induced in exploring coils placed at various radial positions along the poles. The leakage factor σ is the ratio of the voltage per turn induced at the pole head to that induced at the pole base.

The phase difference between the eddy currents in the solid portions and the electromotive forces which produce them could in all probability be determined by means of a transformer, the secondary and core of which is solid metal, cast iron or steel as desired. By observing the power, volts and amperes input to the primary, and allowing for primary leakages and losses, the angle between the eddy currents and their voltages could be calculated.

If the short-circuiting rings are placed near the iron, the large currents in them may produce leakage fluxes which will later set up counter electromotive forces of considerable magnitude. If the rings are far removed from any iron, in general, it is believed that these leakage fluxes will not have very great influence. However, the writer has made no experimental determination of this, but believes that it would be desirable to cause alternating and direct currents to flow through the short circuiting rings and measure the drop in each case. The curve given for determination of the stator end connection leakage was obtained from induction motors and includes the end ring leakage as well as the leakage around the end connections in the stator. In the same way the calculations obtained by means of this curve, used in conjunction with a synchronous motor, should include the end ring leakage as well as the of that stator end connections.

COMPARISON BETWEEN INDUCTION MOTORS AND SYNCHRONOUS MOTORS AT STARTING

The synchronous motor has frequently been compared with the squirrel cage induction motor in regard to the better conditions which obtain in the latter at the instant of starting. It has generally been believed that the poor starting conditions which exist in synchronous motors are due to the large air gap and the fact that only a portion of the stator periphery is covered by the rotor iron. Without doubt these two factors influence the current which is required to produce a definite starting torque. However, after careful observation it is believed by the writer that the leakage reactances in stator and rotor and the rotor resistance have far more influence upon the volt-ampere input at starting than the air gap and rotor configuration. The air gap, in general, influences the volt-ampere input from 10 to 20 per cent, whereas the leakage fluxes are the chief causes of the low power factor which obtains. Moreover, the increase in zigzag leakage due to the reduction in air gap may, in some motors, offset the decrease in volt-ampere input by reduction in magnetizing current. Furthermore there will be less uniformity of torque in the various rotor positions with a small air gap than with a large air gap. In the writer's judgment it is not good practice to sacrifice performance by reducing the air gap with a view of improving conditions at starting.

It is well known that to make satisfactory induction motors which will have leakage fluxes that will consume not more than 30 per cent of the impressed voltage when normal current flows, it is essential to use a large number of small slots in both stator and rotor. On the other hand in synchronous motors it is general practice to use a small number of large slots. If we were to proportion the slots of the synchronous motor in the same manner in which induction motor slots are proportioned and cause the drop due to resistance in the rotor circuit to be equal or greater than that due to leakage fields, the power factor and other characteristics at starting would then compare very favorably with that in squirrel cage induction motors of the same speed and horse power.

CONCLUSION

As far as he knows, the writer is the first to have attempted an analysis of the relations of the various quantities which obtain while starting synchronous motors. In considering a phenomenon so complicated, it is possible that some of the statements which he has made may be incorrect and that some simpler and more accurate methods may be found by others for predicting the power and volt-ampere input during the starting period. The writer would therefore welcome any comments or criticisms which may be of future use in further investigations on this subject.

APPENDIX

I. REACTANCE OF A ROUND SLOT

The area included in Fig. 20 between the bottom of the slot and heighth $x = F = 2\left(\pi r \frac{2\alpha}{2\pi}\right) - r \sin\alpha \cos\alpha$

$$= r^2 \left(\alpha - \tfrac{1}{2}\sin 2\alpha\right) \qquad (56)$$

Taking unit length of slot and one ampere per conductor flux in small area $dx = 0.4\,\pi\left(\frac{F}{\pi r^2}\,a\right)\frac{dx}{2\,y} = d\,\phi$ where a = number of conductors per slot.

But $x = r - r\cos\alpha$ Hence $dx = r \sin \alpha\, d\, \alpha$. Also $y = r\sin\alpha$

And

$$d\,\phi = 0.4\,\pi\left(\frac{Fa}{\pi r^2}\right)\frac{r\sin\alpha\,d\,\alpha}{2\,r\sin\alpha} = \frac{0.4\,\pi}{2}\left(\frac{Fa}{\pi r^2}\right)d\,\alpha$$

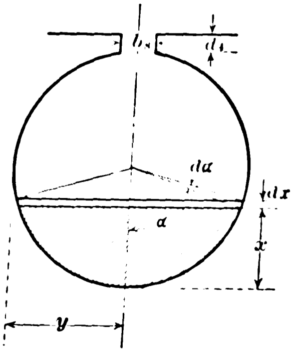

FIG. 20

The interlinkage will then be

$$\int_{\alpha=0}^{\alpha=\pi}\left(\frac{F}{\pi r^2}\,a\right)d\,\phi = L$$

$$L = \int_{\alpha=0}^{\alpha=\pi}\left(\frac{F}{\pi r^2}\,a\right)^2\frac{0.4\,\pi}{2}\,d\,\alpha = \frac{0.4\,\pi}{2}\int_{\alpha=0}^{\alpha=\pi}\frac{r^4\left(\alpha - \tfrac{1}{2}\sin 2\alpha\right)^2 a^2\,d\,\alpha}{\pi^2\,r^4}$$

$$= \frac{0.4\,\pi\,a^2}{2\,\pi^2}\left[\frac{\alpha^3}{3} + \tfrac{1}{4}\left(\frac{\alpha}{2} - \tfrac{1}{8}\sin 4\,\alpha\right) - \left(\tfrac{1}{4}\sin 2\,\alpha - \frac{\alpha}{2}\cos 2\,\alpha\right)\right]_0^{\pi}$$

$$= \frac{0.4\,\pi\,a^2}{2\,\pi^2}\left[\frac{\pi^3}{3} + \frac{\pi}{8} + \frac{\pi}{2}\Big(1 - 1\Big)\right] = 0.545 \times 0.4\,\pi\,a^2 \qquad (57)$$

[If inches be used this becomes

$$L = 0.545 \times 3.19\, a^2] \qquad (58)$$

The reactance per slot, allowing for leakage across opening at top the depth of which is d_4 and width b_s and expressed in henrys is:

$$X_b = \frac{2\,\pi \sim \lambda_b\, 0.4\,\pi}{10^8}\left(0.545 + \frac{d_4}{b_s}\right) a^2 \qquad (59)$$

II. REACTANCE OF STATOR SLOTS WITH ALLOWANCE FOR SHORT PITCH

Consider unit length of slot and one ampere per conductor.

Let a = number of conductors per slot.

Consider first leakage reactance of coil B in Fig. 21.

The following is intended to apply when the currents in A and B are not in phase with each other.

ϕ_1 = flux due to B in lower portion of slot, linking with B.

ϕ_2 = flux due to B crossing slot above B.

ϕ_3 = flux due to A, threading A, but cutting B.

ϕ_4 = flux due to A, above A, and cutting B.

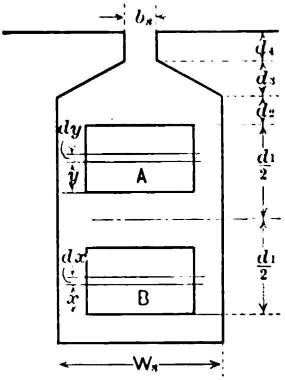

FIG. 21

$$1. \qquad d\,\phi_1 = \frac{x}{\frac{d_1}{2}}\,\frac{a}{2} \times 0.4\,\pi\,\frac{dx}{W_s}$$

$$\text{Interlinkages} = \int_0^{\frac{d_1}{2}} \frac{x}{\frac{d_1}{2}}\,\frac{a}{2}\,d\,\phi_1 = \frac{0.4\,\pi\, a^2}{W_s\, d_1^2}\int_{x=0}^{x=\frac{d_1}{2}} x^2\, dx = \frac{0.4\,\pi\, d_1\, a^2}{24\, W_s} \qquad (60)$$

$$2.\ \phi_2 = 0.4\,\pi\,\frac{a}{2}\left(\frac{d_1}{2\,W_s} + \frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W_s}\right)$$

$$\text{Interlinkages} = \frac{0.4\,\pi\, a^2}{4}\left(\frac{d_1}{2\,W_s} + \frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W}\right) \qquad (61)$$

3.

$$d\,\phi_3 = \frac{0.4\,\pi\,a}{W_s 2}\;\frac{y\,d\,y}{\frac{d_1}{2}} \text{ and } \phi_3 = \frac{0.4\,\pi\,a}{W_s d_1}\int_{y=0}^{y=\frac{d_1}{2}} y\,d\,y = \frac{0.4\,\pi\,a\,d_1}{W_s 8}$$

$$\text{Interlinkages with } B = \frac{0.4\,\pi\,d_1\,a^2}{16\,W_s}\cos\omega \qquad \textbf{(62)}$$

where ω = angle between currents in A and B

$$4.\ \phi_4 = \frac{0.4\,\pi\,a}{2}\left(\frac{d_2}{W_s} + \frac{d_4}{W_s} + \frac{2\,d_3}{b_s + W_s}\right)$$

Interlinkages with B

$$= 0.4\,\pi\,\frac{a^2}{4}\left(\frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W_s}\right)\cos\omega \qquad \textbf{(63)}$$

For three-phase with six-phase winding and for a pitch between $\frac{2}{3}$ and full pitch, $\omega = 60°$ and $\cos\omega = \frac{1}{2}$

Total interlinkages for B, three-phase = **(60)** + **(61)** + **(62)** + **(63)**

$$= 0.4\,\pi\,a^2\left[\frac{19}{96}\,\frac{d_1}{W_s} + \frac{3}{8}\left(\frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W_s}\right)\right] \qquad \textbf{(64)}$$

For two-phase we obtain, allowing for $\omega = 90°$ and $\cos\omega = 0$,

$$0.4\,\pi\,a^2\left[\frac{1}{6}\,\frac{d_1}{W_s} + \frac{1}{4}\left(\frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W_s}\right)\right] \qquad \textbf{(65)}$$

Now consider coil A when there is a phase difference between currents in A and B.

ϕ_2 = flux due to B, linking with A.
ϕ_3 = flux due to A, threading A and linking with A.
ϕ_4 = flux due to A, above A, linking with A.

$$1.\ \phi_2 = \frac{0.4\,\pi\,a}{2}\left(\frac{d_1}{2\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right) \qquad \textbf{(66)}$$

Interlinkages

$$= \frac{0.4\,\pi\,a^2}{4}\left(\frac{d_1{}^*}{4\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_4} + \frac{d_4}{b_s}\right)\cos\omega \quad (67)$$

2. $$d\,\phi_3 = \frac{0.4\,\pi}{W_s}\,\frac{y}{\frac{d_1}{2}}\,\frac{a}{2}\,dy$$

$$\text{Interlinkages} = \int\left(\frac{a}{2}\,\frac{y}{\frac{d_1}{2}}\right)d\,\phi_3 = \frac{0.4\,\pi a^2}{W_s\,d_1{}^2}\int_{y=0}^{y=\frac{d_1}{2}} y^2\,dy = \frac{0.4\,\pi}{24}\,\frac{a^2 d_1}{W_s} \quad (68)$$

3. $$\phi_4 = \frac{0.4\,\pi\,a}{2}\left(\frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right)$$

$$\text{Interlinkages} = \frac{0.4\,\pi\,a^2}{4}\left(\frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right) \quad (69)$$

Total linkages for A for three-phase

$$= 0.4\,\pi a^2\left[\frac{7}{96}\,\frac{d_1}{W} + \frac{3}{8}\left(\frac{d_2}{W_s} + \frac{2\,d_3}{(b_s + W_s)} + \frac{d_4}{b_s}\right)\right] \quad (70)$$

For two-phase, interlinkages

$$= 0.4\,\pi\,a^2\left[\frac{1}{24}\,\frac{d_1}{W_s} + \frac{1}{4}\left(\frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right)\right] \quad (71)$$

When using short pitch, if we drop back by electrical angle $\beta = \omega$ the two coils in all slots will have currents differing in phase by angle ω. For any pitch between this and full pitch, there are $\frac{N_1}{2\,n}\,\beta\left(\frac{n}{180°}\right) - B$ coils per phase and $\frac{N_1}{2\,n}\,\beta\left(\frac{n}{180°}\right)$ A coils per phase, where N_1 = total number of stator slots and n = number of phases.

---

*The fact that this is $\frac{d_1}{4\,W_s}$ instead of $\frac{d_1}{2\,W_s}$ is because not all of conductors in A are cut by ϕ_3 threading A. This brings in the *average* value. The result may also be proven by a simple integration.

In addition there are $\frac{N_1}{n}\left(1 - \frac{\beta\, n}{180°}\right)$ slots per phase in which the currents in the two coils are in phase with each other, and for which the interlinkages are:

$$0.4\,\pi\, a^2\left(\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right) \qquad \textbf{(72)}$$

For a three-phase winding the total interlinkages per phase are from equations (**64**), (**70**) and (**72**):

$$0.4\,\pi\, a^2\left\{\left[\frac{19}{96}\,\frac{d_1}{W_s} + \frac{3}{8}\left(\frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W_s}\right)\right]\frac{N_1}{2\,n}\,\frac{\beta}{60°}\right.$$

$$+\left[\frac{7}{96}\,\frac{d_1}{W_s} + \frac{3}{8}\left(\frac{d_2}{W_s} + \frac{d_4}{b_s} + \frac{2\,d_3}{b_s + W_s}\right)\right]\frac{N_1}{2\,n}\,\frac{\beta}{60°}$$

$$\left.+\left[\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right]\frac{N_1}{n}\left(1 - \frac{\beta}{60°}\right)\right\}$$

After reduction this becomes:

$$\frac{0.4\,\pi\, a^2\, N_1}{n}\left\{\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s} - \frac{\beta}{60°}\right.$$

$$\left[0.198\,\frac{d_1}{W_s} + \frac{5}{8}\left(\frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right)\right]$$

If we allow an approximation of $0.208\,\frac{d_1}{W_s} = \frac{1}{3} \times \frac{5}{8}\,\frac{d_1}{W_s}$ instead of $0.198\,\frac{d_1}{W_s}$, we obtain for three-phase:

$$\frac{0.4\,\pi\, a^2\, N_1}{3}\left\{\left[1 - \frac{5}{8}\left(\frac{\beta}{60°}\right)\right]\left[\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right]\right\} \qquad \textbf{(73)}$$

And for two-phase, we may similarly derive, allowing also a slight approximation:

$$\frac{0.4\,\pi\, a^2\, N_1}{2}\left[1 - \frac{3}{4}\left(\frac{\beta}{90°}\right)\right]\left[\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s}\right] \qquad \textbf{(74)}$$

The slot reactance for three-phase is:

$$X_{s_1} = \frac{2\pi \sim \lambda_s p S\, 0.4\, \pi a^2}{10^8} \left[\frac{d_1}{3\, W_s} + \frac{d_2}{W_s} + \frac{2\, d_3}{b_s + W_s} + \frac{d_4}{b_s} \right] \left(1 - \frac{5}{8}\, \frac{\beta}{60^\circ}\right) \quad (75)$$

And for two-phase:

$$X_{s_1} = \frac{2\pi \sim \lambda_s p S\, 0.4\, \pi a^2}{10^8} \left[\frac{d_1}{3\, W_s} + \frac{d_2}{W_s} + \frac{2\, d_3}{b_s + W_s} + \frac{d_4}{b_s} \right] \left[1 - \frac{3}{4}\, \frac{\beta}{90^\circ}\right] \quad (76)$$

III. End Connection Reactance

Let us first assume that there is one coil per slot. There are then $S a$ conductors per pole per phase in each "phase bundle" representing a group of conductors, and there are $\frac{p}{2}$ groups per phase. If ϕ_f represent the flux per inch of free length with one conductor per group and one ampere per conductor, and the length of end connections per coil be $(M.T. - 2\lambda_s)$ where $M.T.$ = mean length of turn and λ_s = gross length of iron, we have for the end connection inductance

$$= L_f = \frac{\phi_f (S a)^2 p}{10^8 \times 2} (M.T. - 2\lambda_s) \quad (77)$$

And the end connection reactance $= X_f = 2\pi \sim L_f$

$$X_f = \frac{(S a)^2 p \pi \sim \phi_0}{10^8} (M.T. - 2\lambda_s) \quad (78)$$

It has been found that the end connection reactance is nearly the same for single layer as for two-layer windings, if the mean turn and other quantities be the same. We are justified, therefore, in using the above equation for two layer windings as well as single layer. The values of ϕ_f may be obtained from Fig. 18.

IV. ZIGZAG REACTANCE

At the instant of starting, leakage lines of force emerge from the stator teeth, cross the air gap, enter the rotor poles and return to an adjacent stator tooth without interlinking with any rotor conductor. Similarly, leakage flux emerges from the rotor without cutting the stator conductors. This flux has been given the name of zigzag leakage and is well known to induction motor designers.

Modifying the results obtained by C. A. Adams* to suit our notation we obtain:

$$\phi_z = \frac{0.84\,\lambda}{\Delta}\left[\frac{(W_t + C_1 W_s) + (W_{t_2} + C_2 W_{s_2})}{2\,\lambda} - \frac{1}{2}\right]^2 \tag{79}$$

In this ϕ_z is the leakage flux from tooth tips with one ampere per conductor in one slot per centimeter length; λ = average tooth pitch in the stator and rotor; Δ = single air gap in centimeters; W_t, W_{t_2} W_s and W_{s_2} are respectively the tooth and slot widths for primary and secondary; C_1 and C_2 are the Carter coefficient for fringing from Fig. 19.

The inductance is:

$$L_z = \frac{\phi_z\, a^2\, \lambda_s\, p\, S}{10^8}$$

$$= \frac{a^2\, \lambda_s\, p\, S \times 0.84\,\lambda}{10^8\quad \Delta}\left[\frac{(W_t + C\, W_s) + (W_{t_2} + C_2\, W_{s_2})}{2\,\lambda} - \frac{1}{2}\right]^2 \tag{80}$$

As $\left(\frac{W_{t_2} + C_2\, W_{s_2}}{\lambda_2}\right)$ is nearly equal to unity if the rotor slots be partly closed, (λ_2 being rotor slot pitch) we may write, after substituting 1 for this expression:

$$L_z = \frac{0.84\,\lambda\, a^2\, \lambda_s\, p\, S}{10^8\quad \Delta}\left[\frac{W_t + C_1\, W_s}{2\,\lambda}\right]^2$$

$$= \frac{0.21\, a^2\, \lambda_s\, p\, S}{10^8\, \Delta\lambda}\,(W_t + C_1\, W_s)^2 \tag{81}$$

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*See C. A. Adams: *Design of Induction Motors*, TRANSACTIONS A.I.E.E. 1905, page 665.

And the reactance =

$$X_s = \frac{0.21\, a^2\, \lambda_s\, p\, S\, 2\, \pi \sim}{10^8\, \Delta\, \lambda} (W_t + C_1\, W_s)^2$$

$$= \frac{1.32\, a^2\, \lambda_s\, p\, S \sim}{10^8\, \Delta\, \lambda} (W_t + C_1\, W_s)^2 \qquad (82)$$

If inches be used,

$$X_s = \frac{3.35\, a^2\, \lambda_s\, p\, S \sim}{10^8\, \Delta\, \lambda} (W_t + C_1\, W_s)^2 \qquad (83)$$

V. TOOTH TIP LEAKAGE

To distinguish that leakage flux which crosses the air gap when the pole is opposite the stator from the leakage around the teeth when they are situated between the poles, we shall call the former "zigzag" and the latter "tooth tip" leakage.

We may derive an expression for the tooth tip leakage by assuming that this leakage flux travels in the arcs of circles and in straight lines. The leakage flux which encircles one slot in small distance dx (Fig. 22) is:

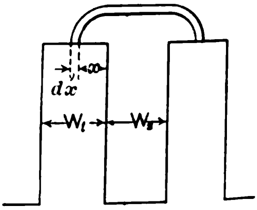

FIG. 22

$$d\,\phi = \frac{(0.4\, \pi\, a)\, dx}{\pi\, x + W_s}$$

And the interlinkages =

$$L_t = \int a\, d\,\phi = 0.4\, \pi\, a^2 \int_{x=0}^{x=W_t} \frac{dx}{\pi\, x + W_s} = \frac{0.4\, \pi\, a^2}{\pi} \log_\epsilon \frac{(\pi\, W_t + W_s)}{W_s}$$

or

$$L_t = \frac{0.4\, \pi \times 2.3}{\pi} a^2 \log_{10} \left(\frac{\pi\, W_t}{W_s} + 1 \right) = 0.4\, \pi \times 0.73 a^2 \log_{10} \left(\frac{\pi\, W_t}{W_s} + 1 \right) \qquad (84)$$

In order to allow for the shortening of lines and the large area through which the flux passes, it has been found from test that accurate results are obtained by increasing the factor 0.73 to unity.

The above applies to one slot per pole per phase. When there are two or more slots per pole per phase, it has been found from test to be satisfactory to obtain the tooth-tip leakage with two slots per pole per phase. Deriving this in same manner as above for one slot per pole per phase we obtain, after substituting 2 for 1.46 to allow for shortening of lines, etc.; and adding expression in equatiion (84):

$$L_t = 0.4\,\pi\,a^2\left[\log_{10}\left(1 + \frac{\pi\,W_t}{W_s}\right) + 2\log_{10}\left(1+\frac{\pi\,W_t}{2\,W_s+W_t}\right)\right] \tag{85}$$

The tooth-tip reactance per phase is:

$$X_t = \frac{2\,\pi \sim 0.4\,\pi\,a^2\,\lambda_s\,p\,S}{10^8}\left[\log_{10}\left(1 + \frac{\pi\,W_t}{W_s}\right) + 2\log_{10}\left(1 + \frac{\pi\,W_t}{2\,W_s + W_t}\right)\right] \tag{86}$$

$$\text{Or } X_t = \frac{7.9 \sim a^2\,\lambda_s.p\,S}{10^8}\left[\log_{10}\left(1 + \frac{\pi\,W_t}{W_s}\right) + 2\log_{10}\left(1 + \frac{\pi\,W_t}{2\,W_s + W_t}\right)\right] \tag{87}$$

VI. EFFECT OF SHORT PITCH UPON ZIGZAG AND TOOTH TIP LEAKAGE

It may be proven in the same manner as for slot reactance that the effect of fractional pitch of coils is to decrease the zigzag and tooth tip reactance by the factor $\left(1 - \frac{M\,\beta\,n}{180^\circ}\right)$ The zigzag leakage is effective over those portions of the stator which have poles opposite them, whereas the tooth tip leakage appears between poles only. Hence, if u is the polar arc and τ' is the pole pitch at the inner periphery of the stator, the fraction of the stator to which the zigzag leakage applies is $\frac{u}{\tau'}$ and that over which the tooth tip leakage is effective is $\frac{\tau' - u}{\tau'}$

Hence, we may add these two leakage reactances and obtain after simplifying:

$$X_z + X_t = \frac{3.35\, a^2\, \lambda_s\, p\, S \sim}{10^8\, \tau'} \left\{ \frac{u\,(W_t + C\, W_s)^2}{\Delta\, \lambda} + 2.36\,(\tau' - u) \left[\log_{10}\left(1 + \frac{\pi\, W_t}{W_s}\right) + 2 \log_{10}\left(1 + \frac{\pi\, W_t}{2\, W_s + W_t}\right)\right]\right\} \left\{ 1 - \frac{M\, \beta\, n}{180^\circ} \right\} \qquad (88)$$

The above applies when metric system is used and when the number of slots per pole per phase is not less than two. For inch system use 8.5 instead of 3.35; and for one slot per pole per phase, omit $2 \log_{10}\left(1 + \frac{\pi\, W_t}{2\, W_s + W_t}\right)$

VII. COMBINATION OF EQUATIONS TO GIVE THE TOTAL STATOR REACTANCE

By adding the leakage fluxes in the various parts of the stator we have for metric system:

$$X_s = X_{s_1} + X_z + X_t + X_f =$$

$$\frac{7.9 \sim p\, a^2\, S\, \lambda_s}{10^8} \left\{ \left(1 - \frac{M\, \beta\, n}{180^\circ}\right) \left(\frac{d_1}{3\, W_s} + \frac{d_2}{W_s} + \frac{2\, d_3}{b_s + W_s} + \frac{d_4}{b_s} + \frac{0.425\, u\, (W_t + C\, W_s)^2}{\tau'\, \Delta\, \lambda} + \left(1 - \frac{u}{\tau'}\right) \left[\log_{10}\left(1 + \frac{\pi\, W_t}{W_s}\right) + 2 \log_{10}\left(1 + \frac{\pi\, W_t}{2\, W_s + W_t}\right)\right]\right) + 0.4\, S\, \phi_f \left(\frac{M.T.}{\lambda_s} - 2\right) \right\} \qquad (89)$$

For inch system of units use 20 instead of 7.9 and express ϕ_f in lines per ampere *centimeter*.

VIII. SINGLE PHASE REACTANCE

If single-phase current be caused to flow in one leg of the stator winding of a two or three-phase machine, and the stator be provided with short pitch winding, then there will be some slots in which the currents in both coils will flow in the same direction, and other slots in which the current flows in only of two coils. By proceeding with a method similar to that given for polyphase machines with polyphase currents, we obtain a result similar to equation (76):

$$X_{s_1} = \frac{2\,\pi \sim \lambda_s\, p\, S\, 0.4\, \pi\, a^2}{10^8}\left[\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{W_s + b_s} + \frac{d_4}{b_s}\right]\left[1 - \frac{3}{4}\,\frac{\beta\, n}{180^\circ}\right] \tag{90}$$

This holds for either two or three phase, a four phase winding being used for former and a six phase winding for the latter.

To obtain the total reactance with single phase current in one phase only of a polyphase stator, the rotor being removed, we must allow for the tooth tip and end connection leakages, the derivations of which are given in this appendix, and obtain with the metric system:

$$X_s = \frac{7.9 \sim p\, a^2\, S\, \lambda_s}{10^8}\left\{\left(1 - \frac{3}{4}\,\frac{\beta\, n}{180^\circ}\right)\left[\frac{d_1}{3\,W_s} + \frac{d_2}{W_s} + \frac{2\,d_3}{b_s + W_s} + \frac{d_4}{b_s} + \log_{10}\left(1 + \frac{\pi\, W_t}{W_s}\right) + 2\log_{10}\left(1 + \frac{\pi\, W_t}{2\,W_s + W_t}\right)\right] + 0.4\, S\, \phi_f\left(\frac{M.T.}{\lambda_s} - 2\right)\right\} \tag{92}$$

If inches be used, substitute 20 for 7.9 and express ϕ_f in lines per ampere centimeter.

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SELECTION OF A WATER WHEEL UNIT

BY O. B. COLDWELL

INTRODUCTION

One of the most interesting problems with which the engineer of a company utilizing water power has to deal is the selection of the hydraulic equipment for his plant.

With the exception of the tangential wheels used in high head work on the Pacific Coast and a few other sections of the United States, it might be said that, for a good many years, most of the water wheels used in this country were located on streams near tide water and operated at heads below 60 feet (18 m.) Water wheels during this period were manufactured very largely along so-called " cut and try " lines and there were no well-developed principles of design. The experience gained during these early years of water turbine building and the knowledge derived through testing and operating such wheels has contributed very largely to the development of the art of water wheel building as it is known today.

Water wheels of this early period were for the most part used in mills of one sort or another to drive machinery which did not demand a very high degree of speed regulation. High efficiencies were occasionally obtained, but usually but for one point of load or for an exceedingly short range of load.

In recent years, due to the more general utilization of the water powers of the country and to the perfection of high-tension transmission of electricity, there have been many developments on the upper stretches of our power streams where the slope in feet per mile is very much greater and higher heads are more common. The operating heads of these plants range from say 60 to 400 feet (18 m. to 122 m.) for intermediate heads, from 400 to 1,000 feet (122 m. to 305 m.) for high heads and from 1,000 to perhaps 2,500 feet (305 m. to 762 m.) for extreme high heads.

Changed conditions are now met with. Many of these modern plants are of the hydroelectric type, requiring a nicety of regulation which was not known in the early period. Economy in the utilization of water becomes an important factor due to the characteristics of stream flow and the necessity of utilizing the available water to the maximum possible extent for the purpose of keeping the cost down to a minimum. In many such developments that part of the total cost brought about by the fixed charges on the investment exceeds greatly the part due to operation, and it is, therefore, important that the output be as large as possible. On account of the characteristics of the loads ordinarily imposed upon hydroelectric plants, the extent to which water can be stored has a marked influence upon the cost of generation in such plants.

Due to the various important factors mentioned above, there has been gradually perfected the highly specialized engineering science of water wheel design.

The object of this paper is not, by any means, an attempt to tell how to design a water wheel, but rather to discuss the features entering into the particular design which will best meet the conditions for which it is intended, and to point out the information which should be furnished by the purchaser to the waterwheel designer to enable him to plan the most efficient unit.

Although we have passed from the earlier period mentioned above into the later, in which a more thorough appreciation of the water wheel problem is required, it still remains a fact that in many instances very little engineering is being used in the selection of water wheels. This is perhaps due to a certain extent to the practice of manufacturers themselves in issuing trade catalogs. These catalogs contain information regarding the discharge of water and horse power developed at given heads by various sizes of runners, but do not take into consideration such factors as variations in speed, variations in head, or other features which may have a large influence on the selection of the proper wheel. As a result, due to the custom of relying on catalogs in the past, many water wheels at present are being ordered directly from these catalogs without due regard and study being given to the conditions which should enter into the selection of the wheel.

In the following discussion an attempt is made to show that in general more thought should be given and more precise methods applied in selecting water wheel units.

ELEMENTARY HYDRAULIC PRINCIPLES

Having made the foregoing presentation of the scope it is intended to cover in this paper, there will now be brought to your attention a few elementary hydraulic formulas which will be employed later in the discussion. The elementary principles which are involved in these formulas should preferably be known and understood by the one selecting the wheel in order that he may properly cope with the questions which he should solve and be able to more intelligently place his order. The formulas given here are not, by any means, all of the formulas which enter into the complete solution of the hydraulic problem.

To begin with, a water wheel is a device which is placed in the path of falling water for the purpose of abstracting energy possessed by that water, due to its fall and weight, and delivering as much as possible of same to the shaft as mechanical energy.

The energy possessed by the water may be expended and made manifest as power as follows:

1. By allowing a quantity to pass from a higher to a lower level practically without velocity.
2. By the momentum possessed by a quantity of it traveling at a velocity caused by the head.
3. By pressure of the water due to head acting on an area through a space.

What usually takes place is a combination of these ways of expending hydraulic energy and making it manifest as power.

Total head is the difference in elevation between head-water and tail-water and is usually expressed in feet. This total head may be divided in general into three parts, as follows: friction head, discharge head, and effective head.

Friction head is that part of the total head which is applied in overcoming the friction in the water passages leading to and away from the wheel, as in the passage away through the racks, entrance to penstock, in the penstock itself, through the guides and buckets, and in the discharge tubes.

Discharge head is the head at which the water leaves the draft tube and enters the tail-race. In well designed wheels this is usually of small magnitude, but it is readily seen that this head is an absolute loss.

Effective head is the part of the total head left to be applied to the wheel itself for effecting the energy transformation after the friction and discharge heads are disposed of.

In the case of Francis turbines, the effective head includes the draft head or effect of draft tube; a tangential wheel has no draft tube.

Friction head loss in a steel pipe is found approximately by the following formula:

$$\text{Friction head} = \frac{l\,v^2}{3{,}000\,d}$$

l = length of pipe in feet
v = velocity in pipe in feet per second
d = diameter of pipe in feet

When the quantity of water available in cubic feet per second and the effective head acting on the wheel are known, the approximate horse power is given by the following formula:

$$\text{h.p.} = \frac{\text{quantity} \times \text{effective head}}{11}$$

This assumes a wheel efficiency of 80 per cent.

The stream flow upon which the plant rating is based should receive careful consideration and study. If possible, accurate flow data over a number of years should be obtained. Many expensive mistakes have resulted from not giving sufficient weight to this matter.

Other fundamental formulas which might be mentioned here are:

$\text{h.p.} \propto \sqrt{h^3}$
$\text{rev. per min.} \propto \sqrt{h}$
Quantity in cubic feet per second varies as $\sqrt{h}$

Velocity in feet per second $= c\sqrt{2gh}$ where c is a constant having values dependent upon conditions of discharge. It is unity in value when water is discharged freely through a perfect nozzle, and in such a case, the velocity is the same as that acquired by a freely falling body and equals approximately $8\sqrt{h}$.

It might be said that the formula $v = c\sqrt{2gh}$ is the most important of all hydraulic formulas, as it enters into all calculations and designs of water wheels.

TYPES OF WATER WHEELS

We will now briefly mention some types of water wheels and the principles on which they act.

a. Gravity Type. This type of wheel includes breast, overshot and undershot wheels. The efficiency of these wheels is often quite good, but the speed and power are extremely low, and this type is, therefore, not adapted to ordinary present-day conditions. We will, on this account, give it no further consideration.

b. Impulse Wheels. This type of wheel includes the Pelton and Girard wheels. They are kinetic energy wheels, that is, the momentum of the mass of water in its impact with the runner buckets is the main principle utilized in the energy transformation.

In the Pelton type, the water strikes tangentially upon the buckets, while in the Girard types, the water passes through the runner radially outward; an extremely careful design is necessary for this type.

c. Francis Type. This wheel is a combined potential and kinetic energy wheel, the water passing either inwardly or outwardly through the runner. The wheel rotates partly from velocity action and partly from reaction due to pressure and consequent acceleration in the buckets. The so-called Smith, American, Holyoke, Jolly, Hercules, McCormack and Victor turbines are well-known wheels of this type. They received the above names years back when the so-called " cut and try " methods were used rather than theoretical design. This does not mean that these wheels are not good wheels. Much credit is due to the enterprise and achievements of the pioneer manufacturers responsible for their development.

DESIGN AND CALCULATIONS

Hydraulic principles properly applied bring the design of a water wheel within the full grasp of the engineer. Hydraulic formulas contain many constants and coefficients, and it has taken time, patience and experience to gain a correct knowledge of the proper values of these. But once having gained a knowledge of them for various types of nozzles and surfaces, a full knowledge of velocity relations and correct design can be arrived at.

In general, the calculations necessary in designing a water wheel runner will be left to the manufacturer and will not be taken up here, but we will discuss briefly the manner in which the speed of a turbine runner is affected by the angles of the buckets and guides, as we will use this later.

Reference may now be made to the sectional drawings Figs. 1, 2 and 3, and the corresponding runners, Figs. 4, 5 and 6. These sketches show the general designs of the guides and runners for three types and angular relations of same. The diameter is the same for each runner.

Let A equal the angle between the tangent to the periphery of the runner and the direction of the flow of the water as it leaves the guides.

Let B equal the angle between the tangent to the periphery of the runner and the entering edge of the runner bucket.

Let V equal peripheral velocity of the runner in feet per second.

Let H equal effective head in feet.

Let D equal diameter of runner in feet.

Then

$$v = 52\sqrt{H}\sqrt{\frac{\sin(A+B)}{\sin B\cos A}} \text{ (approximately)}$$

$$\text{rev. per min.} = \frac{60\,v}{3.41\,D}$$

A consideration of these two formulas clearly indicates that the diameter of the runner and the rev. per min. depend upon the angles chosen. Therefore, with a given diameter, to obtain rev. per min. angles must be chosen to suit and the design of the bucket made to correspond.

It is convenient to use in the process of design a head of one foot as a basis for calculations. Having made calculations for unity head, values for other heads are readily obtained by using the three fundamental formulas given heretofore.

$\text{h.p.} \propto H^{\frac{3}{2}}$
$\text{rev. per min.} \propto H^{\frac{1}{2}}$
$Q \propto H^{\frac{1}{2}}$

The choice and design of a particular type of runner to suit some given fixed condition can be based upon what is known as " specific speed " of the runner. The formula for specific speed is

$K = \dfrac{\text{rev. per min.}\sqrt{H}}{H\sqrt[4]{H}}$ and may be defined as: the speed at which the runner will operate when delivering unity horse power under unity head.

A given specific speed comprehends a particular design of one type of runner only. The designer fixes the angles A and B for each particular specific speed and thereby arrives at standard designs based upon specific speed. Probably no two designers would use precisely the same angles, and, therefore, velocity relations, bucket widths and openings will vary in runners intended to give equivalent performance. The variation, however, is not great.

Let us consider Figs. 1, 2 and 3. Fig. 1 is a runner of low reaction type which would be used on relatively high heads. Notice that the angle A of water leaving the guides is small, and the angle B of the bucket is greater than 90 degrees. These angles are selected to give a low peripheral velocity of the runner. If the values of the angles, which are approximately 14 degrees and 110 degrees, are used in solving the velocity equation given above and H is taken as unity, it will be found that v equals about 50 feet per second for this particular runner.

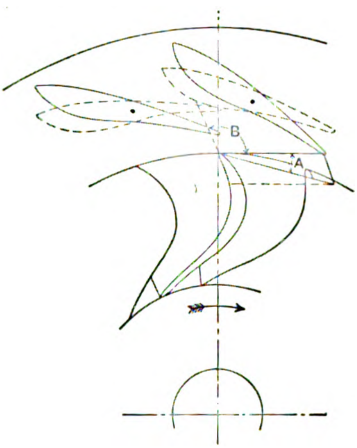

FIG. 1
(See Fig. 4 for Runner)

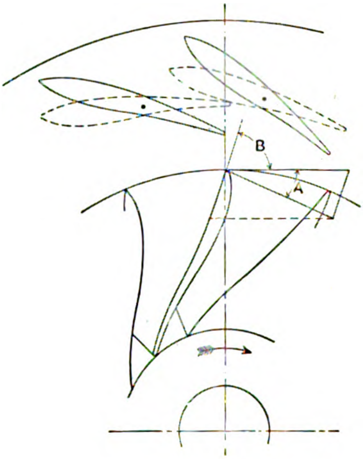

FIG. 2
(See Fig. 5 for Runner)

Fig. 2 is a runner of moderate reaction and is a type which would be used on lower head than the runner of Fig. 1. The angles in this case are selected to give a higher peripheral velocity of the runner. If values of the angles A and B, which in this case are approximately 23 degrees and 73 degrees, were substituted in the velocity formula, it would be found that v equals about 56 feet per second.

Fig. 3 is a runner of high reaction, and would be used on lower heads than the runner of Figs. 1 and 2. The angles in this case are selected to give very high peripheral velocity. Their values are approximately 42 degrees and 46 degrees and the value of v if worked out by the formula is found to be about 71 feet per second.

A comparison of Figs. 1, 2 and 3 shows that as the type of runner changes from low reaction to high reaction the bucket angle changes from a forward curved bucket to a backward curved bucket. It is, therefore, evident that in order to get a high peripheral velocity, a backward curved bucket must be used.

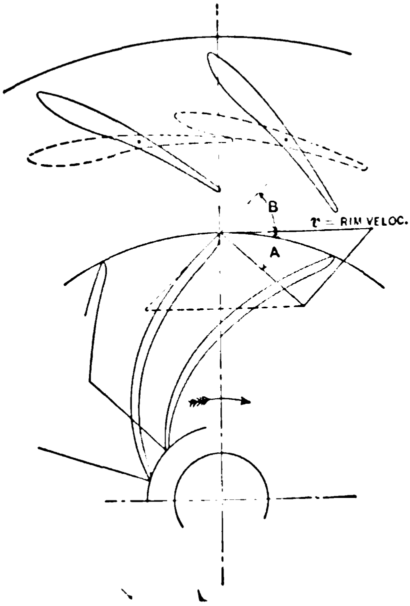

FIG. 3
(See Fig. 6 for Runner)

Comparison of Figs. 4, 5 and 6 shows that in the case of the low reaction runner the width of the bucket is small, while in the case of the high reaction runner we have a very wide bucket for the accommodation of the larger quantities of water necessary. For relatively low power wheels, angles are used to give relatively low speeds, since these wheels are ordinarily used on high head work and small quantities of water are met with. For relatively high power wheels angles are used to give relatively high speeds since these runners are ordinarily used on low heads.

It will be noted that the runner in Fig. 4 is one with a specific speed of $K = 20$; in Fig. 5, $K = 45$; in Fig. 6, $K = 75$.

Francis turbines can be used for values of K as low as 12; for lower values tangential wheels should be used. This limiting value, however, is not well defined.

A manufacturing company ordinarily has available a number of types of runners, each of which has a particular value of K. Each one of these types is used for certain conditions and what is good in one case would probably not be suitable in others. The reasons for this will be brought out more in detail later on.

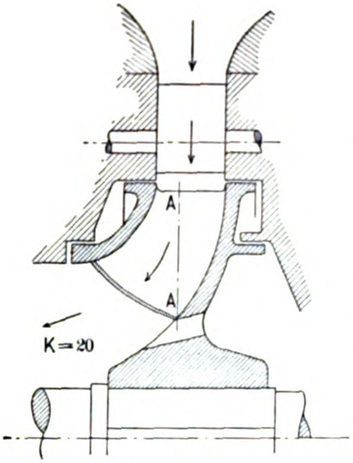

FIG. 4
(See FIG. 1 for Section A-A)

Fig. 7 is entitled "Comparative Efficiency Chart." On this chart the load on the runner is plotted in per cent of its full load, while the efficiency is plotted in per cent of the efficiency at which the wheel operates at full load. Curves for $K = 20$, $K = 45$ and $K = 75$ are plotted. It is readily seen on examining these curves that the efficiency will depend very greatly on the type selected. Let us say that we have a type No. 2 wheel installed, that is, a runner with $K = 45$; it will be noted that when this runner operates so as to give 60 per cent of its full load the resulting efficiency is 103 per cent of its efficiency at full load. If its full load efficiency is say 82 per cent, then the efficiency of

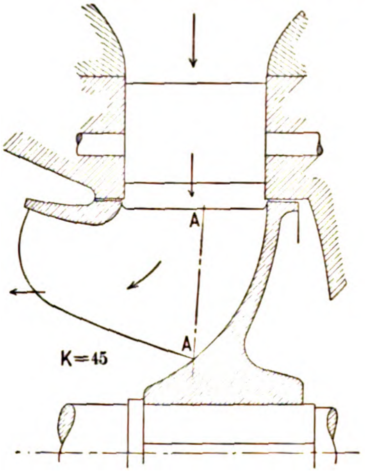

FIG. 5
(See Fig. 2 for Section A-A)

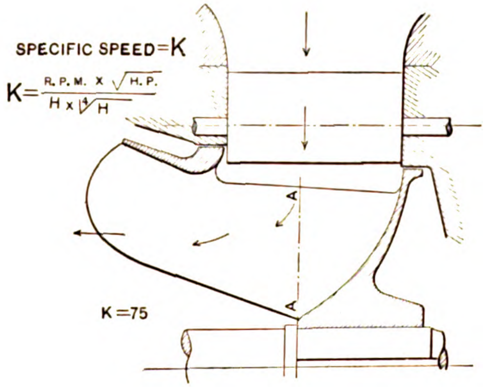

FIG. 6
(See Fig. 3 for Section A-A)

this runner when operating at 60 per cent of full load is 103 × 0.82 = 84½ per cent.

Type No. 1 is used on high head work, No. 2 on medium head work and No. 3 on relatively low heads. It is readily seen by examining the comparative efficiency chart that the efficiency which will be obtained by the employment of these different types varies through a considerable range.

A runner with K = 45 could not be used for very high head work and would, therefore, not enter into consideration for a plant which is going to operate at say 600 feet (180 m.) head. The principal reason why this runner could not be used with a head of 600 feet is that it would be structurally weak for that purpose. In the same way it is readily seen that a runner with K = 75 would not be suited for the high head work. On the other hand, a runner designed for a high head wheel with K = 20 could be used on a lower head, but in all probability would not be so used for many other reasons.

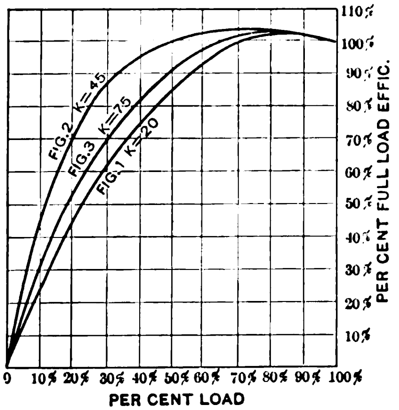

Fig. 7.—Comparative Efficiency Chart

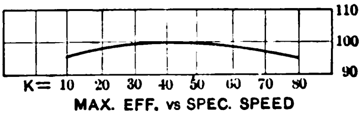

Fig. 8

It is interesting to note, from Fig. 7, that where K = 20 with loads varying from 70 to 100 per cent of full load, the per cent of full load efficiency varies from 100 to 103 per cent. If therefore, the full load efficiency of this particular runner is 82 per cent, the actual efficiency between 70 per cent and full load would be somewhere between 82 per cent and 0.82 × 103 or 84½ per cent.

Let us consider Fig. 8. Here we have plotted the maximum actual efficiency against specific speed. It has been found by experiments which have been made by a number of manufacturing companies from time to time that the specific speed resulting in the highest efficiency is somewhere between $K = 40$ and $K = 50$.

A consideration of the factors entering into the design of water wheel runners, and of tests which have been made on various designs, shows that it is not possible to secure as high efficiencies, even though the operating conditions be the most favorable, for specific speeds which are higher or lower than the specific speeds between $K = 40$ and $K = 50$. Experiments have also shown that there is a certain best speed for each particular type of runner, which speed gives 100 per cent power. At all other speeds, either higher or lower, the power is not so great. The variation of power for changes in speed, however, is different in magnitude for different types.

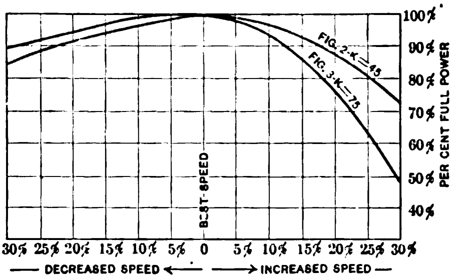

FIG. 9.—EFFECT ON POWER OF CHANGE IN SPEED
Based on Constant Head

Fig. 9 shows this for two different runners, one where $K = 45$, the other where $K = 75$. In this diagram the best speed is shown at the center ordinate as occurring at 100 per cent full power, and it will be noted that as the speed is made higher or lower than this best speed, the power drops off for both types of runner. In the case of the runner $K = 75$, it drops off considerably more than for the type $K = 45$. For instance, an examination of the charts show that an increase in speed of a Type 2 runner, with $K = 45$, of 10 per cent above the best speed, decreases the horse power 4 per cent while a decrease of 10 per cent from the best speed decreases the power about 2 per cent. For a runner with $K = 75$, the horse power is decreased 6 and 4 per cent respectively.

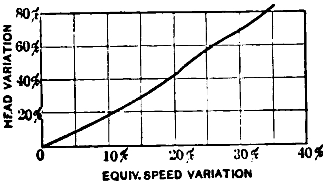

FIG. 10 (See Fig. 9)

In Fig. 10 is given a curve showing the relation between variation in head and equivalent variation in speed. This is really a graphical expression of the formula rev. per min. $\propto \sqrt{H}$ or the equivalent expression rev. per min. = (a constant) $\sqrt{H}$. It will be noted by examining this chart that for a variation in head of 20 per cent there is an equivalent speed variation of 10 per cent. For a variation in head of 40 per cent there is an equivalent speed variation of nearly 20 per cent. This curve will be of use later on in our discussion.

With information such as the foregoing at hand, we should be able to select the best speeds, power, ratings, etc., for use in any given installation.

NUMBER OF UNITS IN THE PLANT

In order that a plant may work to best advantage on the load it has to carry, it must be designed to accommodate the characteristics of that load. In making this determination, a careful study should be made of the load curve and the load factor. There are also a number of other matters of importance entering into this particular subject; for instance, the question of whether or not the plant being designed is to operate alone or in parallel with other plants, whether there is to be a spare unit provided, etc. It is not intended to enter into any lengthy discussion of this subject at this time. Unless the purchaser has reliable information for arriving at a decision on the number of units to be used in the plant, it is advisable for him to secure the assistance of an engineer familiar with such subjects.

SIZE OF GENERATORS

The generator should have a rated output approximately the same as the most economical capacity of the water wheel. It is assumed that an effort will be made to operate the generator as near as possible to its rating. It must be remembered that the most economical point of the wheel varies for different specific speeds. Even though the rev. per min. may not be determined and the specific speed not yet calculated, it can be at once found out from the curve that the maximum horse power of the wheel divided by the kw. rating of the generator should vary from 1.5 to 1.9. This is obtained by dividing the maximum horse power by the horse power at the most economical point and then again by 0.746 to reduce kw. rating. It may thus be said that the maximum horse power of the wheel divided by the kw. rating of the generator will vary from 1.5 to 1.9, depending upon the type of runner to be used. Manufacturers could, therefore, make up a tabulation of the value of this coefficient for their different types of runners. In the first approximation the value of this coefficient might be taken as 1.75, about the average value, and the kw. rating of the generator determined. Later on this could be corrected. The matter of overload should be kept in mind when this point is being worked out.

STANDARD SPEED OF GENERATORS

The electric manufacturing companies can supply tables of speeds for standard generators. Generators with frequencies of 25 and 60 cycles are the most common in use. It is not necessary to give such a table in this paper as it would be altogether too large if it covered all of the standards in use by the electric manufacturing companies. In such a table furnished the writer recently there are to be found for some of the more common sizes of generators met with in modern plants as many as 5 or 6 speeds standardized for each size. For instance, one company has made and is prepared to make a 1750-kw. generator of water wheel type for 150, 180, 300, 514, and 600 rev. per min. and for full load voltages of 600, 2,300 and 11,000-volts. Several speeds would be considered by the designer before making a choice, and the reasons governing the choice will now be considered.

WHAT SPEED OF UNIT IS BASED UPON

The following elements enter into the selection of the speed of the unit: (*a*) head, (*b*) characteristic efficiency, (*c*) runner balancing, (*d*) speed regulation, (*e*) variation in head, (*f*) durability of design. We will discuss these points in order.

a. Head. The head is a most important factor in the selection of the speed. Low heads and attendant low velocities permit of a design of bucket to handle large quantities of water. In such a runner, thin warped buckets of ample size and large openings can be used. These buckets are, relatively speaking, structurally weak. High heads and consequent high velocities make necessary a simple design of bucket, thicker material, and, therefore, relatively small quantities of water. Strength, therefore, must be carefully considered in determining the diameter and speed of a runner. In general it may be said that for proper strength and design, the following specific speeds may be used for any head below the maximum head given.

SPECIFIC SPEED *K* rev. per min.	MAXIMUM HEAD feet	 meters
68 to 75	50	15
50 to 68	100	30
35 to 50	200	61
25 to 35	400	122
10 to 25	600	183

This tabulation is not by any means fixed and is merely given as a guide. If the specific speed figures out for any given head as greater than the values given above, two runners should be used. If two runners are used, the specific speed must again be figured out with a horse power one-half of that used before. If head were the only determining factor, the specific speed could be chosen from the above table and the rev. per min. calculated from the formula.

b. Characteristic Efficiency. It has already been shown that different values of *K* result in a different efficiency characteristic. From our formula it is noted that specific speed varies with rev. per min., hence for any given horse power and head the rev.per min. fixes the specific speed, and the efficiency which is obtained from a runner with this specific speed both for full load and for partial loads. The particular speed characteristic desired, therefore, has much to do with selection of the speed of the runner.

c. Balancing. A single runner can be designed so as to balance thrust. This is some times desirable. With a single runner we have a lower specific speed and, therefore, consequent large diameter of runner. This should be considered by the designer and used where possible. The question of thrust does not enter into consideration with a pair of runners, as these are placed on a shaft as right and left-hand runners and the thrust of one runner is neutralized by that of the other. It is often found, however, that when a pair of runners is used, other conditions of the design must suffer and perhaps to the disadvantage of the installation. In making a proper selection of speed, therefore, the question of balancing is of importance.

d. Speed Regulation. Speed regulation is often times the most important item in fixing the speed. The lower the speed the larger are the diameters and weights of the rotating element and, therefore, the greater flywheel effect of the unit. When the load on the unit is changed the speed varies directly with the flywheel effect. It is therefore often desirable to use a lower speed, fixing this speed by the degree of regulation desired. Extra flywheel effect can be obtained by the use of a flywheel, but this is generally undesirable and if possible should not be considered on account of the danger due to high pressures on bearings, etc.

e. Variation in Head. This is a common condition in low head plants. In hydroelectric plants the speed must be kept constant, even though the head does vary. In the case of pulp grinding mills, speed variation is not of so great importance.

We have already shown in Figs. 8 and 9 that different speeds have different characteristics of power and efficiency when the runners operate under heads other than the heads they were designed for, and lower speed than that given in some manufacturers' standard table of speed may oftentimes be used to advantage and might mean a considerable increase in the output of the plant. At the same time the initial cost may be greater and in such cases a proper balance between cost and benefits must be found.

To get a full conception of the effect of variable speed let us take an example:

Example. A certain water plant has installed in it a water wheel runner of type No. 3, $K = 75$, which is designed to deliver 1,000 h.p. maximum at 200 rev. per min. when operating at 40-ft. (12m.) head. This particular plant is so located, however, that the head varies due to floods, and at times the operating head drops down from 40 to 24 ft. (7m.) The plant is a hydroelectric plant, and the generators driven by the water wheels require a constant speed of 200 rev. per min. in order to operate properly on the electric system connected to them. Let us investigate what will happen under these conditions. One of our fundamental formulas states that the horse power varies as $H^{\frac{3}{2}}$. Therefore, at 24-ft. (7-m.) head our 1,000-h.p. wheel will give $\dfrac{1{,}000}{\left(\frac{40}{24}\right)^{\frac{3}{2}}} = 465$ h.p. This calculation, however, is based on the assumption that we allow the wheel to run at the proper speed for 24-ft. (7-m.) head, which speed would be in accordance with the formula: rev. per min. $\propto H^{\frac{1}{2}}$. Thus, $\dfrac{200}{\left(\frac{40}{24}\right)^{\frac{1}{2}}} = 155$ rev. per min.

Now, as a matter of fact, we do not want to allow this change in speed for the reason stated above, and as this is the case, we must sacrifice some of our power. If, therefore, we decrease the head from 40 to 24 ft. (12 m. to 7 m.) which is a drop in head of 16 ft. (5 m.) or a change of 40 per cent in head, we will have, in accordance with the chart in Fig. 10, a corresponding speed variation of approximately 20 per cent.

Referring now to Fig. 9 we note that for an increase of 20 per cent in speed, there is a corresponding decrease in power for a Type 3 runner of 25 per cent. We would sacrifice, therefore, when operating at these changed conditions, 25 per cent of the power which the runner operating at its best speed for this head possesses, that is, 25 per cent of 465 h.p. or 115 h.p. We would have left, therefore, when operating the wheel under these changed conditions as brought about by flood, the difference between 465 h.p. and 115 h.p., or 350 h.p. If a runner of type No. 2 $K = 45$, should be installed in this plant instead of a runner of Type No. 3, it is readily seen from Fig. 9 that when operating under the changed conditions brought about by the flood, the loss in power, instead of being 25 per cent, would be but 12 per cent, which is a loss of 57.5 h.p. The power, therefore, of a type No. 2 wheel, if installed in this plant, and operating under the altered conditions, would be 465 h.p. minus 57.5 h.p., or 407.5 h.p.

f. Durability. In high head installations particularly, pitting of the runner blades takes place, due to shock of water against the buckets, or high velocity, and the operation of the unit much of the time at other than the most economical point. This being the case, it is quite important to consider durability when making the selection of the proper speed of runners. Let us again consider the formula $v = 52\sqrt{H}\sqrt{\frac{\sin(A+B)}{\sin B \cos A}}$. If we select a value of $B = 90$ degrees the trigonometrical expression under the radical sign becomes unity, changing the formula into $v = 52\sqrt{H}$ which is the formula for discharge from a simple nozzle. It is found when a value of $B = 90$ degrees is selected that the pitting is reduced to a minimum. From the above deduction this would be expected.

In the foregoing discussion we have considered a large number of items which enter into the subject of water wheel design and have indicated the desirability of getting some good engineering advice when selecting a unit. We have not, by any means, covered all of the points which enter into this interesting subject, nor would it be possible to do so in the time at our disposal. It is not expected that in general the buyer should acquaint himself with all of the various formulas and curves which have been dwelt upon. It has been necessary, however, to review them in a brief manner in order to lead up to the recommendations to the purchaser selecting a water wheel unit.

GENERAL DESIGN OF UNIT

The conditions which must be met with in the particular plant where the installation is to be made determine the general make-up of the unit. Water wheels may have but a single runner, may have a pair of runners, or for low heads, four or even six runners to the unit. In some places a vertical design of unit is required, while in others horizontal units best suit the conditions in many instances, it is merely a matter of taste, but in most cases there are features which influence the selection of horizontal or vertical units.

When a pair of wheels is used, it must be determined whether an outward discharge or a bottom center discharge is the more desirable. Both schemes are used, one involving a single draft tube, the other, two draft tubes.

When low heads are met with, open flumes are possible and a properly arranged open flume may take the place of the closed flume. In high head work it is, of course, necessary to use a closed flume.

The housing enclosing the runners may have various forms. For instance, it can be a scroll case design or a cylindrical design; it can be made out of cast iron, cast steel or steel plate or may even be formed in concrete. The scroll case has high economy on account of the water passages being designed so as to give a proper increase in velocity before the water enters the runners.

There are many other types of flumes, such as the cone shaped type. This type has ordinarily high economy, but has the disadvantage of a bearing which is not readily accessible.

Consideration must be given as to whether the inlet of the unit is to be beneath the floor line or above; the general question of accessibility of the various parts of the unit, the location of the governor, and many other points must be given attention. Racks of ample area must be provided at the intake in order that there may be low velocities through same and little loss of head. The pipe line must have careful consideration and proper velocities must be selected.

In plants with long pipe lines, the speed regulation and the consequent pressure variation is of great importance, as the latter has to do with the strength necessary and, therefore, the design of the pipe line. In some cases, pressure regulators are necessary. Again, surge tanks may be used. The draft tube must have proper attention and the tail-race be such as to give low velocities. If the tail-race is restricted, the total head is affected.

In order that the purchaser and water wheel manufacturer may have at hand when the wheel is being designed data covering all of the points which should enter into the design, it has been thought advisable to give a list of questions which should be filled out as completely as possible by the purchaser and sent to the manufacturing company for use when making his wheel.

DATA TO BE GIVEN TO WATER WHEEL MANUFACTURER

1. Number of units.
2. Horse power of water wheels.
3. Kw. of generator.
4. Total head.
5. Open flume or closed flume.
6. If closed flume, what is number of pipes?
7. What kind of pipe?—wooden stave, steel or concrete?
8. Diameter of pipes.
9. Effective head (unless design of all water passages to and from wheel is left to water wheel manufacturer).
10. Head water elevation.
11. Floor elevation.
12. Tail water elevation.
13. Head variable, if so, what is normal operating head?
14. If head is variable, what is the range of variation?
15. How important is power and economy at lowest head?
16. Speed of generator, if already decided.
17. If speed of generator is not decided, name speeds which seem to purchaser most desirable and ask recommendations.
18. Flywheel effect of generator.
19. What speed regulation is desired for different load changes?
20. Will units run in parallel with other plants? If so, give general characteristics of such plants.
21. If running in parallel with other plants, can these plants be used to regulate the system?
22. What is the character of load factor?
23. What is the nature of water (silty or clear)?
24. What date shipment of material is desired.
25. Advise if it is expected that manufacturer shall furnish governor.
26. Give sketches of power plant site.
27. Give information as to what is to be expected in the way of guarantees.
28. Give any other information which you think would influence the design of the wheel.

It will not be attempted here to outline the specifications which should be made out to cover the purchase of the water wheel unit, but a list of data which should be supplied by the water wheel company is offered.

DATA TO BE SUPPLIED TO PURCHASER BY WATER WHEEL MANUFACTURER

1. A check of the calculation on effective head.
2. Horse power guarantee at normal head.
3. Guarantee at other heads, if head is variable.
4. Speed guarantee, including runaway speed.
5. Recommendation for best speed if same has not been determined.
6. Speed regulation guarantees.
7. Efficiency guarantees at full load, ¾ load and ½ load.
8. Point of greatest efficiency of wheel and value of same in per cent.
9. Efficiency guarantees for available head conditions.
10. If water wheel manufacturer furnishes governor, give information as to the type, make, power required to operate same, also what variation in speed will not be exceeded before the governor will begin to readjust gates to meet a change of load, either gradual or sudden.

    In what time will governor completely open or close gates?

    Within how many seconds will the speed of the unit be restored to normal?
11. Complete drawings showing machinery proposed.
12. Complete description of machinery proposed.
13. Guarantee of durability.
14. Guarantee of shipment.

CONCLUSION

In submitting for your consideration the foregoing, I have endeavored to impress upon you the importance of giving careful attention to a number of principles which enter into the selection of a water wheel unit. It is quite possible that the ideas of the writer on a number of points which have entered into this discussion may not altogether agree with those entertained by others. He has, however, laid stress upon points which in practice he has found of value in selecting water wheels. It is hoped that the subject matter will form the basis of a beneficial discussion of this most interesting subject.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16–20, 1912.

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IRRIGATION IN THE SPOKANE VALLEY

BY L. J. CORBETT

The first time I made the trip through the Spokane Valley was on a hot July afternoon nearly twelve years ago. Most of it was dry pasture land, but here and there were fields of grain, many of them already cut, bound and shocked. This seemed unusual to me for that time of the year, for in my own neighborhood, some 80 miles (128 km.) south of this, the grain would not be ready to cut for some four weeks yet. Under these conditions it looked quite dry. parched and dusty. Houses were few and far between, and the bright sun shining on the whiteness of dry grass and stubble made the tree-covered hills at each side of the valley look far more inviting.

A July traveler of 1912 will see a far different view spread before him. He will pass orchard after orchard of peach, apple and pear trees, tracts of small fruits, vegetables and melons, and will see evidence of a plentiful supply of water on every hand. Neat, well built houses are dotted about over the landscape and the appearance of comfort, sociability, and thrift is general. As for the few stretches of dry grass he may pass through, if he looks closely the chances are that he will find them studded with white stakes with cabalistic characters—the marks of the surveyor.

These changes, like similar changes which have occurred in various parts of our more arid west, have all taken place within the last decade, and are due to the capital expended and the progress made in irrigation enterprises. Some of these have been gravity systems, but a large and increasing number have consisted of wells in the valley floor, equipped with electrically driven pumps.

About 1902 a gravity canal was built leading water from Liberty Lake to a tract of one and one-third square miles (3.4 sq. km.), which was called Greenacres. The remarkable results which followed this demonstration of the use of water on the valley soil, has from 1904 on led many other companies and individuals to put in irrigation systems of one sort or another, and place the land thus benefited upon the market at greatly increased prices. At first gravity was the prevailing method of accomplishing this result, but sources thus available were

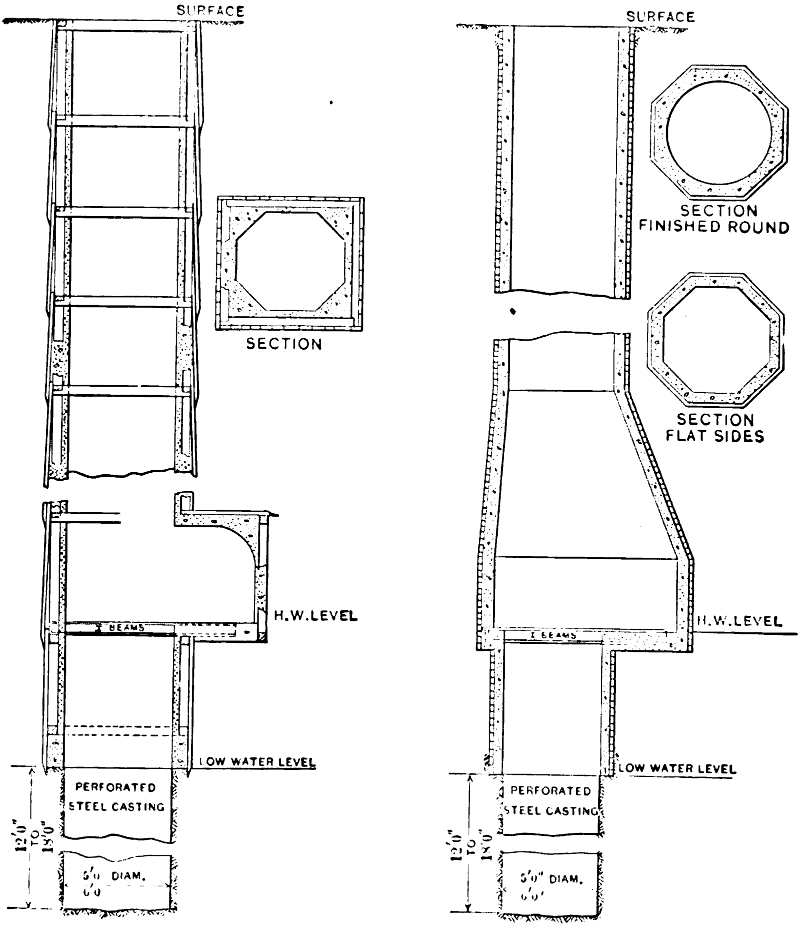


FIG. 1 FIG. 2

TYPES OF WELLS IN THE SPOKANE VALLEY

limited, and recourse was had to the underground supply. The depth of the water table, from 100 to 150 ft. (30.4 to 45.7 m.) in a number of cases, made electric drive the most convenient.

At the commencement of the use of the deep wells, the vertical shaft centrifugal pump was used, but later installations have in general used horizontal direct-connected units set in a tunnel or enlargement of the well. (See Figs. 1 and 2). These sketches show the two general forms of well in use, the two types being due to the different methods of the local well diggers. The square form is timbered in exactly the same manner that a mine shaft is timbered, and the tunnel or recess is driven on one or both sides of the main shaft as required by the machinery to be installed. The other type is sunk in the shape of a hexagon or octagon, the curb consisting of two inch lumber properly jointed to form the figure. As the excavation progresses the curbing follows. This method has the advantage that a minimum of material is excavated for a given clearance, and the sides offer a smooth surface for one side of the forms in case of the concreting of the well, and thus again a minimum of concrete is required for a lining. In the square well the large timbers, 6 by 6 in. (15 cm.) or 8 by 8 in. (20 cm.) vertically placed in the corners and horizontally every 6 or 8 ft. (1.8 m. or 2.4 m.) between bents, make necessary a much greater amount of concrete to give as great strength in the weakest place as in the case of the other form.

With the hexagon or octagon type of well, however, when a space is required larger than that given by a straight well it is more difficult to start a tunnel, and when this form is used, if the equipment to go into it is known at the time of digging, the requisite size of recess is obtained by flaring out the diameter of the well as the proper depth is approached, which gives it a shape like the neck of a bottle.

Usually the approximate level of the water sheet is known, and as this is approached a smaller well is driven from the large well floor, and is lined to a depth of 12 to 18 ft. (3.6 to 5.5 m.) below the water surface by a perforated steel casing while the floor of the large well is lowered to a distance above the water level known by experience in the locality to be safe from high water. This is then concreted and I beams receive the bed plates of the pumping equipment and support the weight of the delivery pipe.

The irrigation season in the Northwest is usually from three to four months. For that reason, and to lessen the demand upon the power, all electrical pumping projects are equipped with a separate system for domestic supply. In some cases this means a separate piping system throughout the tract, with small pipes suitable for heavy pressure connected with wooden tanks erected on wooden towers to give the requisite head for house supply. In these cases the irrigation water is lifted no farther than is necessary to carry it through the low pressure pipes, open canals and flumes to the discharge openings at the high points of the various tracts.

This duplication is practised where the land level is fairly uniform in character. Where differences in elevation are relatively great, the piping for the two systems is combined, and all the water, including that required for irrigation, is pumped against a high head. This of course refers only to smaller projects where the amount of land at different levels is not sufficient to justify the expenditure of the amount necessary to put in separate wells and pumping systems.

Some of these domestic supply pumps are of the centrifugal type and others are of the cylinder type, duplex or triplex. These pumps are directly connected or geared to motors of from 5 to 40 h.p.

The level of the water table in the Spokane Valley bears a certain relation to the water in the river but maintains its individuality as a separate stream. The river bed is so cemented that it is almost impervious. A hole dug a few feet from the water's edge will not fill from the river for many days, while in the water-holding formation, the gravel of which it is composed is very free. The underground stream reaches its flood height several days later than does the river above it, and the change in level from low water to high water is less, being from seven to eight feet, (2.1 to 2.4 m.), as noted in wells at various locations in the valley, while the river variations are often twice that amount in portions of the stream.

I once had occasion to get data on the level of the water table in an undeveloped portion of the valley and found that at the Idaho-Washington state line the water table was about 35 ft. (10.6 m.) below the level of the river surface. At the eastern part of Opportunity the water table was 7.5 ft. (2.3 m.) below the water surface of the river. At Pasadena Park, which is located a short distance above the dam of the Spokane City water works, the water table was 2 ft. (61 cm.) below the level of the river.

In 1904 the U. S. Geological Survey took measurements of the discharge of the Spokane River at the lower end of Coeur d'Alene Lake, at Greenacres, (half way down the valley), and at the gage station in the City of Spokane. These measurements cast some light on the question of the magnitude of the underground stream. The readings were taken on September 16.

At the outlet of Coeur d'Alene Lake, width 450 ft. (137 m.); area of section 1,043 sq. ft. (96.89 sq. in.); mean velocity, 0.93 ft. (28.3 cm.) per second; discharge, 969 second-feet (295 second-meters).

At Greenacres, about 17.5 miles (28.1 km.) below this point, the measurements were, width, 254 ft. (77.4 m.); area of section, 1,181 sq. ft. (107.9 sq. m.); mean velocity, 0.62 ft. (18.8 cm.) per second; discharge, 727 second-feet (222 second-meters).

At Spokane the readings were, width, 201 ft. (61.3 m.); section, 1,696 sq. ft. (157.5 sq. m.); velocity, 0.96 ft. (29.3 cm.) per second; discharge, 1,630 second-feet (497 second-meters).

This showed 900 second-feet (274 second-meters) more in the river at Spokane than at Greenacres, only a small portion of which may be accounted for as entering, not the river directly, but the valley, by gravity systems from Liberty and Newman Lakes. The Spokane Water Works is located above the lower station, so the water supply of the city of Spokane, which at this time was pumped directly from the river, should be added to this amount. This quantity would probably be in the neighborhood of 50 second-feet (15 second-meters).

It will be noticed that there was some 240 second-feet (73 second-meters) more at Coeur d'Alene than at Greenacres, the greater portion of which, it is believed, leaves the river before it is much below Post Falls, nine miles (14.5 km.) below the lake.

The quantity of water which can be pumped from some of these wells is shown in the following data from the largest system using the underground supply. This is Opportunity, with 2,500 acres (1,010 hectares) under irrigation.

Well No.	Size of pump		Discharge		Depth		H.P. of motor
	Inches	Centimeters	gal. per min.	liters per min.	feet	meters	
1	8	20	1,600	6,060	124	37.8	100
2	10	25	3,500	13,200	109	33.2	150
3	10	25	4,000	15,100	110	33.5	200
4	8	20	4,000	15,100	95	28.9	175
5	12	30	5,000	18,900	124	37.8	300
6	10	25	3,500	13,200	105	32	175

Total capacity of pumps, 21,600 gal. per min. Total motor h.p., 1,100.

The well numbers above given may not agree with the numbers given them by the company; they refer merely to the order in which the data were obtained.

These pumps all draw their water from the lower portion of the well, which is lined with a perforated steel casing, in most cases 6 feet (1.8 m.) in diameter and extending 12 to 18 feet (3.6 to 5.5 meters) below low water level. Under these conditions, the level, when pumping, does not fall more than from 18 inches to 2 feet (0.46 to 0.61 meter). It will be noticed that the combined capacity of the pumps is 21,600 gallons (81,760 liters) per minute, or 48 second-feet (14.6 second-meter) for the 2,500 acres (1,010 hectares) or 1 second-foot to each 52 acres, with a combined motor capacity of 1,100 h.p. It is to be understood, however, that it is not expected that this load shall ever be concentrated at one time, as the various wells are located some distance apart and are utilized as the water superintendent directs, with the two ideas in mind of keeping down the power bills and of satisfying the wants of the irrigators.

Vera, an adjoining tract under the same management, has at the present time 1,200 acres (485 hectares) under irrigation, served by four wells equipped as follows:

Well No.	Size of pump		Discharge		Depth		
	Inches	Centimeters	gal. per min.	liters per min.	feet	meters	H.P. of motor
1	10	25	4,500	17,030	117	35.6	300
2	8	20	3,500	13,200	100	30.4	200
3	15	38	4,500	17,030	150	45.7	300
4	12	30	4,000	15,100	135	41.1	250

Total capacity of pumps, 16,500 gal. per min. Total motor h.p., 1,050 h.p.

Here we have 16,500 gallons (62,460 liters) per minute capacity for 1,200 acres, (485 hectares), or one second-foot (0.3048 second-meter) to each 32.7 acres (13.23 hectares) and 1,050 h.p. capacity in motors. The motors on both these systems take three-phase 60-cycle power at 2,300 volts.

The irrigator usually wants what he wants, when he wants it, and he wants enough of it to rush his work through in a few hours rather than a small stream which will take his attention for several days. Another factor is the soil, a black basaltic loam with considerable gravel, which will assimilate a great amount of water if it is applied slowly, so a small stream soon disappears, and an orchard is left with the upper ends of the rows too wet, before the lower ends receive any water at all, and much is wasted by percolation through the gravel to the water table below. There are occasional rains during the summer months which obviate the need of irrigation for a few days at a time. Pumps are seldom if ever operated at night. This was a selling feature which added to the price of the land as against gravity systems already on the market. No reservoirs are used, so while irrigation is in progress, all water being used is being pumped from the underground supply. These features cause the irrigation load on a power system to be an erratic quantity, subject to high peaks and periods of no load.

The rate at present paid on these two systems is $4.00 per kv-a. per month, subdivided into two fifteen-day periods, based on the ten-minute peak load. The irrigation load extends from May 1 to September 1; the remaining eight months the load consists of the lighting and the power for domestic water supply.

The cost of the plant in these cases is absorbed by the added value of the land. The land is sold in tracts, the unit being ten acres (4.05 hectares). With each acre of land, one share of stock in the water company is conveyed, so eventually, when the land is all sold, the owners of the land operate the water company as a mutual concern. The water contracted for is 14.4 inches (36.5 cm.) in depth in 120 days, commencing May 1. The water is to be delivered at the high point of each 10-acre (4.05-hectare) tract. The cost of operation and maintenance for the season of 1911 was about $6.50 per acre (0.405 hectare.) This does not include interest and depreciation. Exact data on the cost of these systems are not available. An average from the summary of an irrigation census, taken in 1910, places the average cost throughout the valley at $51.00 per acre. I believe that for these systems the cost would be higher than this, probably in the neighborhood of $80.00 per acre. This would include the cost of the domestic supply system, as would also the maintenance charge of $6.50 cover the cost of the domestic service. To allow for interest and depreciation, from $4.00 to $6.00 per year should be added, which would bring the power cost up to from $10.50 to $12.50 per acre per year.

To give some actual figures, on a smaller project in the vicinity, with which I was personally connected, the total amount of land was 330 acres (133 hectares), of which 20 acres (8.1 hectares) was granite scenery, upon which a number of tenacious pine trees clung. The well was located on low ground, where the total depth was only 46 feet (14 m.), the last 11 feet (3.3 m.) of which was below the low water level, and lined with a perforated steel casing, five feet (1.52 m.) in diameter. A wood tank located on the rocks acted as a standpipe and reservoir for the domestic supply, the head pumped against being about 190 feet (58 m.) including friction. A flat at an elevation of 35 to 60 feet (10.6 to 18.3 meters) above the water table, and a bench at an elevation of 100 to 110 feet (30.4 to 33.5 meters), were on one side of the well, while hillsides and benches up to 150 feet (45.7 m.) were located on the other side. In this project, one pipe system only was used for both irrigation and domestic water. The large pump is a 7-inch (18 cm.) two stage turbine type centrifugal pump rated to deliver 1,200 gal. (4,540 liters) per min., or 2.66 second-feet (0.81 second-meters). It is direct connected to a 100-h.p. induction motor, three-phase, 60 cycles, 440 volts. A small triplex pump of 60 gal. (227 litres) per min. capacity, geared to a 5-h.p. motor furnishes the domestic supply for the eight months of the year in which irrigation is not practised. A tunnelled recess was necessary on one side of the well to hold the equipment. This and the well were lined with concrete. Wood stave pipe, from 4 to 10 inches (10 to 25 cm.) in diameter, was used throughout the system.

The cost in this case, counting the amount already expended, and the estimate to finish, will amount to approximately, $16,000, or, distributed among the 310 acres (125 hectares), the plant cost is about $51.60 per acre.

The capacity in this case is less than in the case of the Opportunity and Vera plants before mentioned, being only one second-foot (0.3048 second-meter) to 116 acres (46.9 hectares), while the average for the other systems is one second-foot to 52 acres (21 hectares) and to 32.7 acres (13.23 hectares) for Opportunity and Vera respectively. In the small system, there has been no difficulty, as yet, on account of insufficient capacity, although the condition may arise when every acre is improved, that it may be found expedient to add more capacity, but I think not. It was laid out for 16 hours of service per day.

On account of the high head pumped against, the power bills are high, though the interest and depreciation item is lower than on the other two systems. In this case the company makes a definite yearly charge of $12.00 per acre, though the estimate of cost had been $13.00.

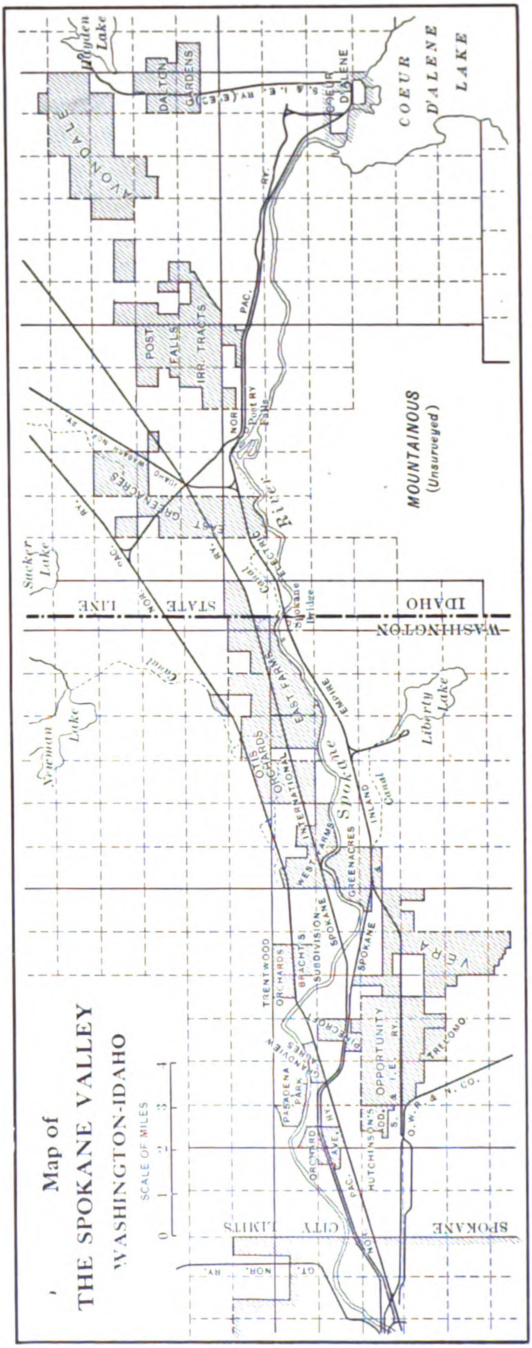
The average amount of water required in this section for miscellaneous vegetables was 12 inches (30.5 cm.) for the season. Taking the cost of operation and maintenance given for the Opportunity-Vera systems as $6.50 per acre, we can compare the cost with that of other systems in other parts of the country.

We have here a direct cost of $6.50 per acre-foot. The average depth of the ten wells being 117 feet (35.6 m.), the cost per foot-acre-foot has been $.0557. This is relatively high and I think is due to the power contracts, the maximum demand being the controlling factor. This type of load being only a small part of the total load carried by the two power companies in this field, there has not been, as yet, a method of rates developed for the best interests of the water users.

I know that some years ago a form of contract for all power loads was general, and was applied also to irrigation systems, of a fixed charge per month per h.p. capacity and a kw-hr. charge on a sliding scale for energy consumed. A method of this kind, if it did not contain provisos regarding time of peak load during which irrigation is prohibited, would seem to me to be the best. Of the two companies supplying this district, one has a power, railway, and lighting load. The lighting peak is a serious thing with this company and it has been its policy to discourage heavy power loads during peak hours and especially irrigation loads, which are for three or four months only, part of which is at times of low water. The other company has railway load only, with no serious peak, and it has been its policy to offer the flat rate.

I have used the figures of the large system rather then those of the small system, for the reason that the number of acres served is greater than the capacity of any one pump, and consequently it may be expected that the electrical load can be regulated to some extent, and the peak upon which the charge is based kept within certain limits. In the case of the smaller system, one pump was to serve the entire tract when it is developed or sold to industrious individuals, and when only about 50 or 60 per cent of it is developed and using water, the peak load is as high as if every acre were in use. The only difference in the plant's operation would be that it would operate more hours per day than it does now.

I might also state that the smaller company, being a smaller consumer, has a less favorable contract, paying $4.00 per electrical h.p. per month, measured on the five-minute peak, the month not being divided as in the case of the larger company.



Irrigated Tracts in the Spokane Valley

The relatively high charges to the water user are not so serious in this locality as they might be in a district farther removed from large centers of population. It is possible for a workingman to live out on a small tract and work in Spokane, taking advantage of the interurban car service and commutation rates. He can have all the conveniences which go with water under pressure, he can have a reasonable amount of electric light free of extra charge, and can develop his land in his spare time. It is not a hardship on him then to pay a yearly charge of $6.50 for his one acre, for his water rent alone in the city would cost him from $9.60 minimum to $15.00 per year for the same conveniences. His electric light would add another minimum of $12.00 per year if he used it. His carfare on the interurban line would not be much greater than his carfare from any home he might have in the city, and the time taken by the trip would be the same.

For a man holding and developing a large number of acres the high charge would be more serious, but such matters adjust themselves from financial considerations, the most profitable crops for the large tracts being the perishable fruits, vegetables, etc., where the nearness to market is an important item and justifies the high cost of land and water. It would be a financial mistake to put the land in hardy apples, for instance, merely because of its convenience to the city. Cheaper land from 50 to 100 miles (80-160 km.) farther away, with cheaper water, provided it can produce as good apples and is located near a railroad, would be a better business proposition. The freight rates under present conditions would be just the same.

There is room here for further development in irrigation, and in the future it will be mainly along the line of pumping from the underground supply, the gravity systems now started, or in operation, being the only ones of that kind which can in the future compete with the pumping systems.

As will be noted from the map, the valley is only about 35 miles (56 km.) long and an average of seven miles (11.2 km.) in width, so it is evident that in time the growth of the city of Spokane will encroach upon a large portion of it. At present, however, a variety of irrigation methods are practised, and amounts of water furnished or prices charged are not uniform.

The conditions under which irrigation is practised modify the economic features, and a difference in structural features from those of other parts of the country is noticeable. The annual precipitation is about 17 inches (43 cm.), the growing season about five months, from 100 to 120 days of which is counted upon for irrigation, instead of 11 months as in the southern portions of the country. The plant must lie idle for eight months, so a reduction in plant cost and consequent interest charge is sought for. This condition is apparent in cheaper distributing works and less of them, and furrows for distribution in many places where pipe would be used further south, a greater allowance for depreciation being granted. The results obtained, however, tend toward the same broad purpose which all engineers should have in view, making two blades of grass grow where one has grown before, to increase our production to keep pace with or exceed our increase in population.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16-20, 1912.

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AN UNDERGROUND SYSTEM AND A FEW DEVELOPMENTS

BY S. B. CLARK

In October, 1908, the Portland Railway, Light & Power Co., after serious consideration of the relative merits of the alternating current and direct current underground distribution, adopted plans for the construction of a complete system of underground conduits and cables within certain limits, which included the principal business section of the city of Portland. The Edison three-wire, 120/240-volt system was adopted, with the exception of a 600-volt distribution system in some sections of the city where the company had at that time heavy 600-volt customers, for both power and light throughout.

The substation feeding the underground district is located practically in the center of the heavily loaded area, being at Seventh and Alder streets, and occupying the first floor and basement of the nine-story general office building of the company. The underground district consists of business houses, hotels, theatres and small manufacturing plants, with a small number of residences on the outskirts.

The subway system is built almost entirely of vitrified clay duct, consisting of two classes; namely, trunk and distributor. Trunk ducts are $3\frac{1}{4}$-in. (7.7 cm.) square bore, and in building up the subway, three-way, four-way and six-way trunk ducts were used in different combinations. In building up with multiple ducts all joints were broken, each joint being wrapped with burlap, dipped in neat cement. A thin layer of sand was used between the tile to act as a cushion and to take up any irregularities, and the whole incased with a three-in. (7.6-cm.) envelope of a 1-3-5 concrete mixture top and sides, with a four-in. (10-cm.) base. Distributor ducts are 2½ in. (7.3 cm.) square bore and in all cases three-way distributor tile was used, either single or in multiple. The same practice, with the exception that a lighter base was used, was followed in the building of the distributor subway as was used in building the trunk.

The first manholes and distributor boxes were built of brick, but owing to the cost and the labor troubles encountered, with the exception of in a few cases where the obstructions were so bad as to hinder the building of the concrete forms, this practice was discontinued. The remainder, or bulk, of the manholes and distributor boxes are built of concrete. Manholes are of different sizes according to the size of subway to be accommodated and the room available. The distributor boxes are more or less standard, being approximately 30 in. (76 cm.) square and three to four (0.9 to 1.2 m.) deep.

Adjacent to the substation, large sized vaults were built to accommodate the necessary incoming and outgoing cables.

Round double covers were used on manholes and square double covers on distributor boxes. Manholes were built at the street intersections where trunk subway was built or wherever necessary for the installation of a feeder. Distributor boxes taking care of the distributor subway only, were built at the street intersections where manholes were unnecessary and at the middle of each block. The city blocks being, with few exceptions, 200 ft. (61 m.), this method provides for a service into the corner of each block and at the center. Services are taken into the buildings through wrought iron pipe from either a distributor box or manhole.

There are in operation three classes of cables; namely, high-tension, 600-volt, and 120/240-volt. All of the high-tension cables are substation feeders or tie lines operating at 11,000 volts alternating current. These 11,000-volt cables are standard 3 x 250,000 cir. mil., varnished cambric, lead-armored cables, connecting to station switches or to overhead lines through station or open-air terminals. Wherever the 11,000-volt cables are exposed in manholes, they are covered with ¼-in. (6.3 mm.) soft asbestos, which, in turn, is closely wrapped with galvanized iron ribbon. The 600-volt class includes commercial distribution, railway feeders and tie lines. The 600-volt commercial system of distribution consists, of feeders treeing off at different points in the different districts supplied with this class of service. The 600-volt commercial distributor cables vary in size from

750,000 cir. mils. to 2/0, and are paper insulated. Distributor cables smaller than 2/0 are rubber insulated as are the service cables. All 240-volt feeder cables run direct from the station to their terminals in the streets and connect into cable feeder boxes, being tied to the mains through fuses.

Feeder junction boxes consist of two types; namely, surface and manhole. The surface type boxes are set in the roof of the manhole, each box having two rings, one positive and one negative, to which the feeder stubs and mains connect through fuses. The boxes also contain terminal fuse blocks for pressure wire connection.

A concentric 1,000,000-cir. mil paper-insulated cable is the standard for this class of feeder, having three pressure wires, laid in with the outer conductor strands, 120 degrees apart. At the station and feeder ends, two single-conductor, 1,000,000-cir. mil cables with two pressure wires each, are used to connect direct to the switch and feeder cable buses; station end single-conductor cables are paper-insulated, while feeder ends are rubber-insulated.

The neutral feeder system is installed very similar to the 600-volt system type; that is, the tree system.

The 240-volt distributing mains, with few exceptions, are 250,000-cir. mil, paper-insulated cable. All mains are tied in with fuses through main junction boxes to the net work of the system, and service cables are spliced solid to the mains. Service cables are of different sizes, depending upon the customer's load, the small sizes being rubber-insulated while the larger sizes are paper-insulated.

The system as a whole gives a total of 113.43 miles (182 km.) of cable of different sizes; 50.22 miles (80.6 km.) of trunk duct; 55.81 miles (89 km.) of distributor duct; and 6 miles (9.6 km.) of service pipes.

The services to the customer are of three different types; namely, basement, face of building, and in the high water area, first floor. Cables upon entering a basement or running to the proper locations above the first floor level are brought into the main line switch which is enclosed in an iron box. Feeds are taken away from this box through conduit into other boxes and connected to the branch blocks enclosed therein. From these branch boxes, gutters made of zinc enclose the leads to the meters. A meterboard is installed in each case for the mounting of these boxes and meters, either singly or for grouping, as the case may be, and the customers wire to these points. In the case of the face of building service, the cable connects direct to cutout blocks enclosed in a weatherproof iron box fastened to the face of the building. Feed wires are carried from this point up to the first story in conduit, and then along the building or buildings, as the case may be, to the condulet outlets. Customers wire to the condulet opening.

In the design and construction of an underground system two important things must be considered; namely, cost of construction and cost of operation and maintenance. The general trend during construction is to build as rapidly and as cheaply as possible, taking care of the present needs, letting the future and the operation take care of themselves. When that future time comes and the problems of operation come up, many things present themselves as different problems to the central station company, which after a time and considerable expense, are satisfactorily overcome.

Large solid underground distribution systems being comparatively new, very little data regarding standard underground construction is available. The reason for this lies chiefly in the fact that no two companies follow the same methods, each separate company, to a great extent, designing its own equipment and apparatus. Because of the fact that the experimental stage of this work is by no means a thing of the past, even the large manufacturers of underground appliances are continually changing their designs in order to keep up with the rapid advancement being made in underground construction.

One of the most important points of underground work is the splicing of the cables. This is no doubt more noticeable with the medium sized systems and where the underground method of electric distribution is only in its infancy. The cable splice itself is, as a general rule, what the individual splicer makes it, and the making of the joints, including both labor and material with the other necessary operations on the cable itself, is one of the most costly operations there is to be found in the construction and operation of the underground system. All cable splicers are at some time given certain instructions regarding the making up of different classes of splices. Although they follow these instructions to a certain extent, they invariably make the splice so that it will " surely hold." It some times happens that the " surely hold " splice is built up so that it will stand thirty times the strain that it was intended for, even the lead sleeve being a great deal too large for the necessary clearance, which means lost time, wasted material, excessive cost, and last but not least, valuable space taken up by bulky splices. Another point to be considered is the fact that splicers all come from places using different methods and systems, each having different ways of making different classes of splices. One individual maintains a certain way of making a certain splice is improper. This in turn causes friction between the men on the work. This same trouble holds good in regard to other classes of underground construction.

The above all points to the standardization, as far as possible, of work, and in getting satisfactory standards before the workmen. The underground division of this company is inaugurating a standard for all operations; these standards being given to the foreman of each gang in the shape of handbooks (small linen blue prints bound in book form) containing all of the necessary detail plans for making and installing all units. The standards most fully developed to date are those of the splices and interior service construction.

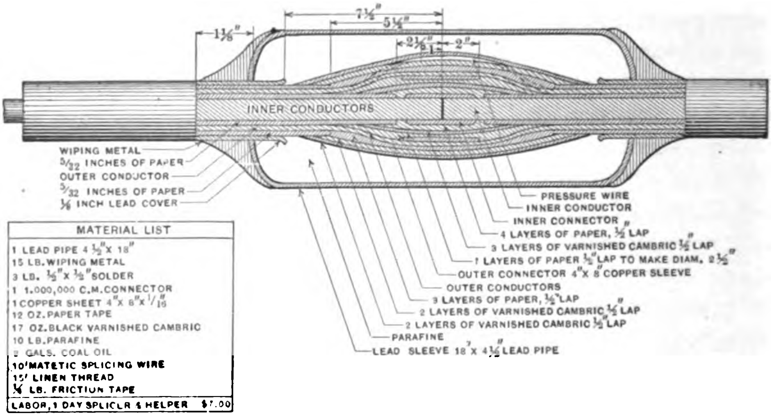
In determining the standard to be adopted a great deal of time was spent in working out each unit. In the standard splice, all of the different materials were subjected to a breakdown test after being wound round the conductor of a 350,000-cir. mil cable. After a test had been applied to the insulation with the temperature of the conductor about 65 deg. fahr., the conductor was heated to about 150 deg., which temperature was maintained from ten to thirty minutes, according to the thickness of the insulation, after which another test was applied. This determined whether or not the properties of the insulating material were changed by the heating of the cable. The different insulating materials that were tested and used on splices are as follows:

Pure cut sheath rubber tape,
40 per cent Para rubber tape,
Gumfaced tape,
Standard splicing gum,
Black varnished cambric tape,
Empire tape,
Paper tape,
Friction tape.

All of these tapes were carefully built around the copper conductor for testing in one layer, two layers, three layers, etc.; one-half lap, separately and in combinations. After taking into consideration the mechanical and electrical qualities, the cost of material and the labor required for handling the different materials, the material which seemed best fitted for each particular splice was adopted. At the regular underground meetings, the splicers were also consulted in regard to the practical end of the work.

Fig. 1 is a reproduction of one of the pages of the standard handbook showing the 2 × 1,000,000-cir. mil, 240-volt concentric cable splice. This standard and operation sheet are followed faithfully by the splicers.

All of the different kinds and classes of splices are handled in the same manner. It is hoped that in the near future material for the splices that are used most frequently will be made up and requisitioned from stock in standard package form. The unit standards are also used in making up estimates and job sheets, and by using the index number of the "standard splice," the number of unit splices and location of each is shown on the manhole record. By doing this under our system of cost records, it greatly facilitates the handling of charges.


7¼"
5¼"
1⅛"
2½"
1
2"
INNER CONDUCTORS
WIPING METAL
5/32 INCHES OF PAPER
OUTER CONDUCTOR
5/32 INCHES OF PAPER
⅛ INCH LEAD COVER
PRESSURE WIRE
INNER CONDUCTOR
INNER CONNECTOR
4 LAYERS OF PAPER, ½" LAP
3 LAYERS OF VARNISHED CAMBRIC ½" LAP
7 LAYERS OF PAPER ½" LAP TO MAKE DIAM. 2½"
OUTER CONNECTOR 4"X 8" COPPER SLEEVE
OUTER CONDUCTORS
3 LAYERS OF PAPER, ½" LAP
2 LAYERS OF VARNISHED CAMBRIC ½" LAP
2 LAYERS OF VARNISHED CAMBRIC ½" LAP
PARAFINE
LEAD SLEEVE 18" X 4½" LEAD PIPE

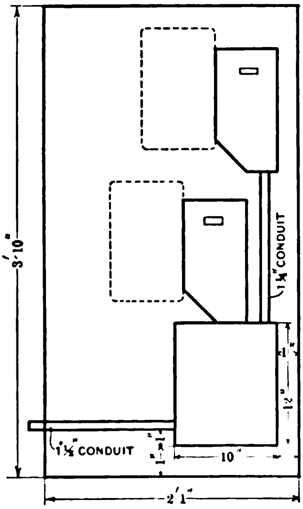
MATERIAL LIST

1 LEAD PIPE 4½"X 18"
15 LB. WIPING METAL
3 LB. ½"X ½" SOLDER
1 1,000,000 C.M. CONNECTOR
1 COPPER SHEET 4"X 8"X 1/16"
12 OZ. PAPER TAPE
17 OZ. BLACK VARNISHED CAMBRIC
10 LB. PARAFINE
2 GALS. COAL OIL
10' MATETIC SPLICING WIRE
15' LINEN THREAD
¼ LB. FRICTION TAPE
LABOR, 1 DAY SPLICER & HELPER $7.00

FIG. 1—STANDARD STRAIGHT CONCENTRIC SPLICE.

Another set of standards that have been developed and found to be successful are those pertaining to the interior service construction. It is the custom of the company to install a complete iron-clad service to and including meters for the consumers in the underground district. These services may consist of but a service switch and one meter, a service switch and meters in multiple, or a service switch and 15 or 20 meters, for individual consumers. All of the different units used, such as meterboards, switch boxes, branch boxes, meter guards, conduit nipples, etc., have been standardized to take care of each individual case as may be necessary. This class of work is estimated, installed and recorded as units, thereby doing away with a great amount of detail work in the office. It also saves a great deal of time in assembling and installing the sets.

Fig. 2 shows a set designed for two meters with cutout blocks for a maximum load of 60 amperes. This is a sheet for the assembling only of the different standards, the details of the different standards being worked out for the shop work only.



MATERIAL LIST.

1-BOARD 25" X 46" X ⅞".
1-60 AMP. BR. BOX STANDARD.
2-1-T METER GUARD
1-1¼"-15¾" CONDUIT NIPPLE.
1-1½"-15¾" " "
8-1¼" " BUSHINGS.
2-1½" " "
3-1¼" " LOCKNUTS.
2-1½" " "
1-1¼" CHASE NIPPLE.
8-1¼"-NO. 10 F. H. BRIGHT WOOD SCREWS.
2-60 AMP. D. P. M. L. 250 V. FUSE BLOCKS.
- AMP. " 250 V. CART. FUSES.
4-1" X NO. 10-24 T. MACHINE SCREWS.
22'-NO. 4 D. B. R. C. WIRE STANDARD.
10'-NO. 2 D. B. R. C. WIRE STANDARD.
½-LB. SOLDER.
1/10-LB. RUBBER TAPE.
⅛-LB. FRICTION TAPE.
¼-GAL. GASOLINE.
1 - NAME CARD.
1 - CARD HOLDER.
4 - RIVETS 3/16 X 3/12.
1/10-LB. SOLDER FLUX.

LAPOR

FOR BRICKWALL INSTALLATION	$6.00

FIG. 2—STANDARD 60-AMPERE DOUBLE TIER SET.

This arrangement also gives us, by a system of numbers combined with the job sheets, a method of keeping the interior service records corrected up-to-date. As far as is known, no other company is using the above system and class of interior construction.

There are any number of other items in underground work that may be handled in a much more satisfactory manner than at present. Every company operating an underground system will in the near future feel more inclined to adopt uniform methods in handling underground work, and when that time comes this work will be handled much more easily than at present, and at a greatly reduced cost.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16-20, 1912.

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ALTERNATING-CURRENT SYSTEMS OF UNDERGROUND DISTRIBUTION

BY S. J. LISBERGER AND C. J. WILSON

In most cities where electric energy is distributed underground, particularly in congested sections, the Edison three-wire, 200-volt direct-current system is used.

COMPARISON OF DIRECT AND ALTERNATING-CURRENT SYSTEMS

Omitting considerations of first cost, the direct-current system is preferable by reason of its simplicity and reliability; also, it is more flexible in operation.

Automatic regulators perform the same functions for the alternating-current feeders that the several bus pressures do in the direct-current system. The direct-current system feeds into a common network, the feeders and mains being tied together through suitable junction and fuse boxes. The load on a direct-current feeder rarely exceeds 300 kw., whereas an alternating-current feeder, for economical distribution, carries ordinarily a load of 1,000 kw. An alternating-current feeder supplies a considerable number of mains, to which cross connection is made.

The secondary systems of alternating and direct current are similar in design. Due to the wide extent of territory covered by the feeder and mains, and to the large load connected to same, suitable emergency ties, junction boxes, oil fuses, etc., must be provided to sectionalize the portions of the system that may be affected, or upon which work must be performed. The necessity for these auxiliary devices is apparent when considering the high potential of the alternating-current system as compared with the low potential of the direct-current system.

REASONS FOR ADOPTION OF ALTERNATING-CURRENT SYSTEMS

This paper is not intended to advocate the application of alternating current to an underground system as against direct current, but to present some reasons why alternating current must sometimes be adopted instead of direct current.

On the Pacific Coast many cities are supplied entirely or in part from hydroelectric transmission systems. In the inception current was distributed overhead at 2,400 volts, two- or three-phase, and transformed to 120/240 volts, single- or polyphase, for light and power. A single substation supplied a wide area. Low rates induced the extensive application of alternating-current apparatus. When city ordinances demanded the undergrounding of wires, operating companies were confronted with the problem of continuing the alternating-current system or changing all the apparatus for use on direct current.

Financial considerations did not admit of a change of system. The necessity of building more substations, resulting in higher investment costs in lands, buildings, station equipment, storage batteries, and the expense of replacing consumers' apparatus, made the engineers reluctant to recommend the adoption of direct current. It should be borne in mind that the cost of installing storage batteries was prohibitive, and without battery standby the advantages of a direct current system were to a certain extent offset. The practice of competing companies was to install an.alternating-current system solely for reasons of first cost. Competition therefore demanded that alternating current be available.

Neglecting the question of competition, there is a growing demand for alternating-current service, particularly for low-voltage sign lighting and other devices which can be used only on alternating current.

The authors in the foregoing have endeavored to outline why alternating-current service must be supplied in underground territories. This paper will cover a description of this system as used in the territories supplied by the Pacific Gas and Electric Company. The discussions will not pertain to conduit or manhole construction, nor any details pertaining to types of cables used.

In certain territories both direct current and alternating current are supplied for lighting and power purposes; in other territories where only alternating current is supplied for lightning and power purposes, direct current, for elevators and other types of apparatus demanding direct current, is supplied at 550 volts, no lighting being carried on this system.

The description following will apply only to the alternating-current installation.

DISTRIBUTION

Systems in General. Where the feeder distribution from substations is 4,000 volts, three-phase, star-connected, both three-phase and single-phase distribution on the mains is used. In three-phase systems 4,000-volt mains radiate from the center of distribution. In the single-phase systems 2,300-volt mains feed from the center of distribution. The transformers are standard subway type, 2,400 volts—120/240 volts. The secondary distribution is 115/230 volts, three-wire supplying light and power to small single-phase motors not exceeding 5 h.p. Where the distribution is three-phase the transformers are connected in banks of three, star to star, delivering a secondary voltage of 120 volts from line to neutral and 208 volts between legs. All lighting is supplied at 120 volts; power at 208 volts, three-phase.

Regulation. With the single-phase primary distribution an automatic induction regulator is connected in each phase, giving excellent regulation, even with severe unbalanced loads. Where the distribution is three-phase, equally good results can be obtained with the installation of a three-phase regulator, due to balanced conditions resulting from the three-phase secondary network.

Cable System. The feeder cables are both 4/0 and 2/0, three-conductor. One neutral wire suffices for several feeders. This neutral is run as a weather proof wire. It is grounded at the station as well as to the lead sheaths of the cables and to the ground plates provided in the manholes. The grounding of the neutral wire at points other than the station, by test, does not cause any interference with regulation.

The primary mains vary in size according to the load, although no conductor smaller than No. 4 is used. Feeder cables are designed for a load of 1,000 kw., although 25 per cent overload may be carried safely for limited periods of time.

Where cables enter either oil fuse boxes or transformers, varnished cambric insulation is always used. All other cables used for feeders or mains are paper insulated. All joints, including connections to the sectionalizing boxes, are wiped.

Junction and Fuse Boxes. The first essential in the successful operation of any system is continuity of service. All systems are more or less subject to interruptions; however, each system should be so designed that these interruptions will be reduced to a minimum, both as to duration and area affected. With this end in view, junction boxes have been developed to provide a means for sectionalizing the cable system, not only when defects occur, but also to isolate parts of the system in order to work with safety on cables that otherwise would be alive.

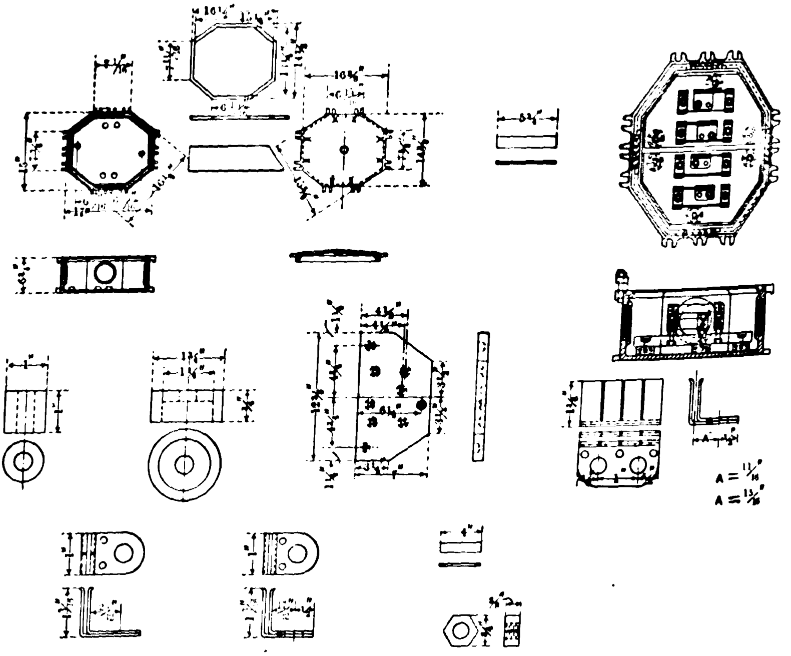
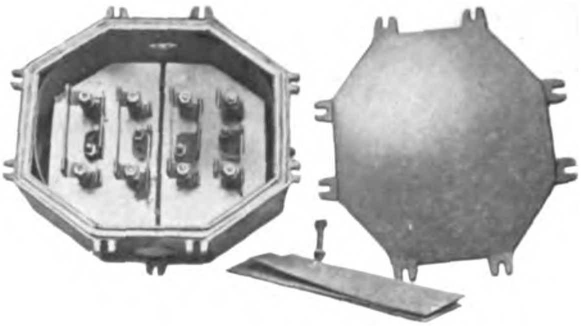


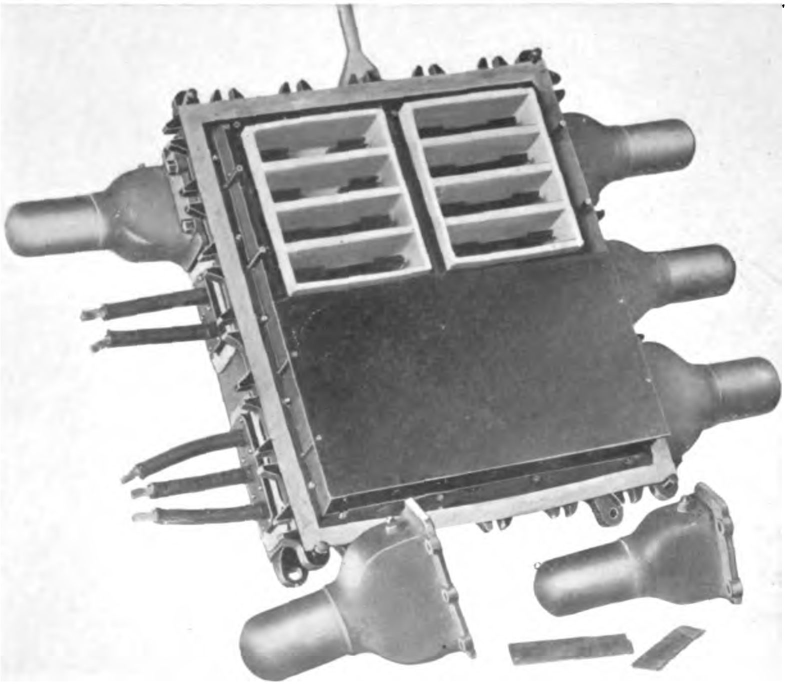
FIG. 1A—DETAILS OF 2,300-VOLT JUNCTION BOX FOR SINGLE, 2 OR 3-PHASE

All junction boxes are made of cast iron with aluminum covers, made waterproof by means of a molded rubber gasket. All boxes are provided with brass nipples, bolted to or screwed into the box, to which the lead sheath of the cable is wiped. Although in many cases submerged under water, no failures due to moisture have been recorded. A fibre insulating material is used as a supporting base for conducting parts in all boxes where the potential is 2,500 volts or less. Marble or slate has proved unsatisfactory. Porcelain is entirely satisfactory for potentials of



[LISBERGER AND WILSON]

FIG. 1.—2,300-VOLT JUNCTION BOX, 1-2-3-PHASE



[LISBERGER AND WILSON]

FIG. 2.—4,000-VOLT THREE-PHASE JUNCTION BOX

4,500 volts, but the cost is not justified on the lower-voltage boxes.

The box shown in Figs. 1 and 1A is used on systems where the potential does not exceed 2,500 volts. This box can be used on single-, two- or three-phase systems by providing it with the proper number of connecting terminals and links. The cables enter from four sides, terminating on studs. Cross connections are made by means of copper links. No fuses are used on the primary system, except on transformers.

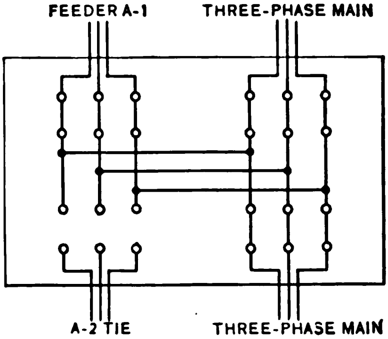


FIG. 2A.—DIAGRAM OF CONNECTIONS, 4,000-VOLT JUNCTION BOX, 3-PHASE FEEDER AND 3-PHASE MAINS

In 4,000-volt systems the box shown in Fig. 2 is used. This box is suitable for distributing either three-phase or single-phase from the three-phase cable, as illustrated in Figs. 2A and 2B respectively. It will be noted in Fig. 2B that the neutral conductor is brought into the box at one side, through a pothead and a wiped joint, for the purpose of excluding moisture. These boxes are designed to carry 200 amperes at 4,500 volts, three-phase. The bus bars in the box are insulated with varnished cambric, in addition to which the bus compartment is filled with a high grade non-flowing insulating compound. The box is sealed at the factory, and when installed only the link compartments and

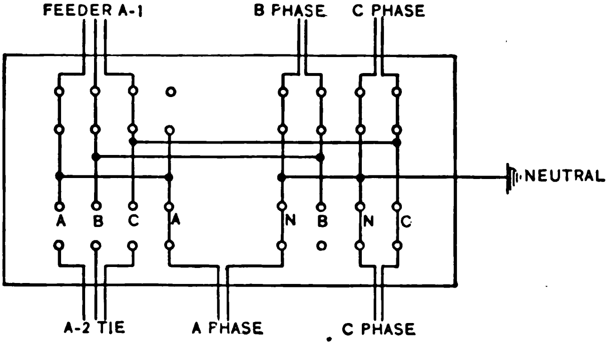


FIG. 2B—DIAGRAM OF CONNECTIONS, 4,000-VOLT JUNCTION BOX, 3-PHASE FEEDER AND SINGLE-PHASE MAINS

the cable terminals are accessible. The link compartments are of porcelain. In the first design the compartments were molded in multiple, but due to manufacturing difficulties individual compartments were substituted in the later designs.

The type of fuse box shown in Fig. 3 is used in connection with the transformers. These boxes are built in two- and three-pole types, for use with single- or three-phase installations. The box is designed for mounting in a horizontal position. Cables are brought into it through angle bosses to the terminals mounted on an ebony asbestos base. The fuse is mounted on a holder consisting of knife-blade contacts held rigid by means of a fibre tube. The fuses are immersed in an oil bath, which covers all the conducting parts. In addition to the oil bath, additional insulation is obtained by means of a treated wood or fibre lining, together with fibre barrier plates attached to the cover.

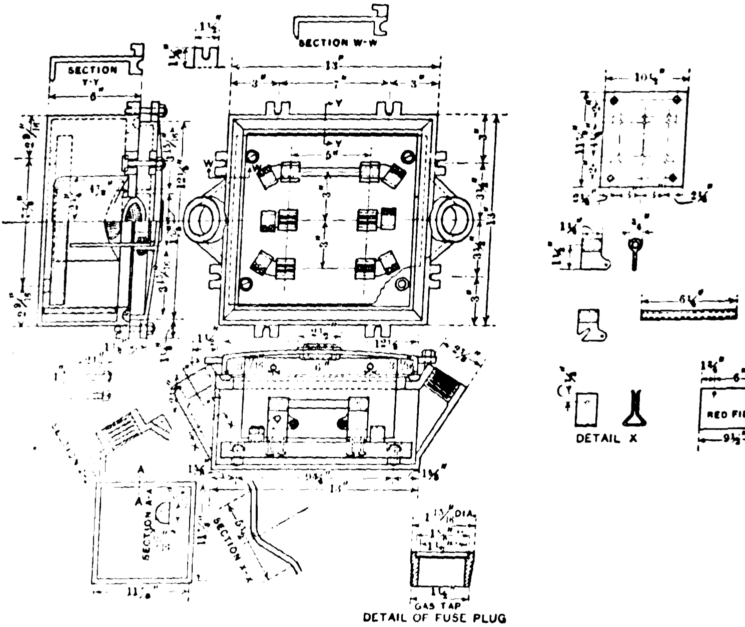
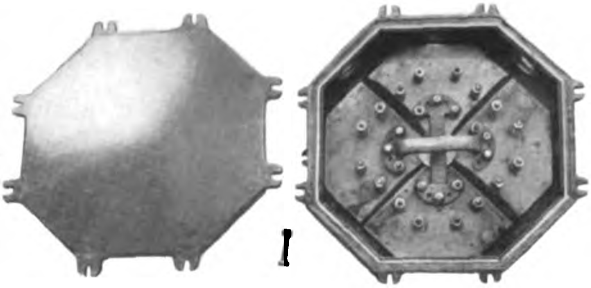


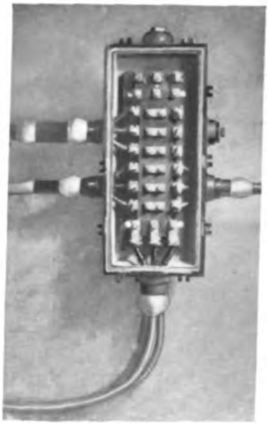
Fig. 3—Details of 4,000-Volt Oil Fuse Box

Before the three-pole, 4,000-volt box was put into service it was carefully tested by blowing fuses as high as 70 amperes at 4,500 volts, three-phase. These tests were made with the box connected directly to the substation bus bar through an automatic oil switch with 6,000 kw. capacity on the bus.



[LISBERGER AND WILSON]

FIG. 4.—250-VOLT FUSED JUNCTION BOX, TWO-POLE



[LISBERGER AND WILSON]

FIG. 5.—250-VOLT THREE-PHASE FUSED JUNCTION BOX.

In the secondary system, where current is distributed for lighting purposes on the three-wire Edison system, junction boxes as shown in Figs. 4 and 4A are used. This box is a combined junction and fuse box, the fuse being bridged from stud to bus bar. Sufficient entrances are provided for transformer leads, intersecting mains and services. This box is designed for loads not to exceed 600 amperes at 220 volts. The neutral is not brought into the box.

The three-phase secondary junction box is shown in Figs. 5 and 5A. This box is designed for 500 amperes, three-phase, 250 volts. Outlets are provided for six 3-conductor cables, thus allowing for transformer leads, four mains and one service. This box is simple in construction, only two patterns being necessary for the bus bar castings. The buses are entirely enclosed and separated by means of fibre insulating strips. Only the fuse terminals are exposed. The terminal lug or block serves the double purpose of a cable terminal and fuse contact. This construction results in an eighteen-pole box, the overall dimension of which is 31 by 16 in. (78.7 by 40.6 cm.). Fibre barriers are inserted in slots in the base to prevent arcing between poles in case of violent short-circuits.

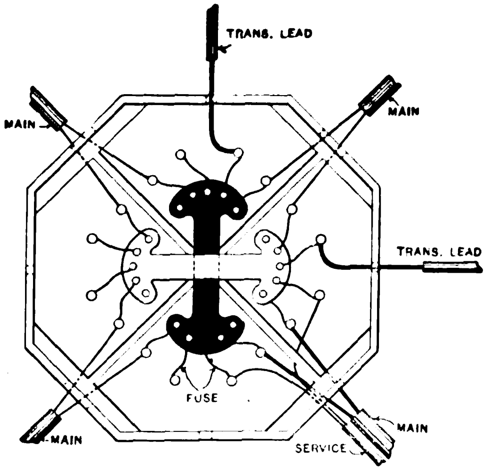


FIG. 4A—DIAGRAM OF CONNECTIONS, 250-VOLT FUSED JUNCTION BOX, TWO-POLE

Transformers. Except in a few vaults located in the basements of large buildings entirely walled off and entered only through a door from the sidewalk, subway type, oil-insulated, air-cooled transformers are used. Transformers vary in size from 10 to 150 kw. Where single-phase lighting load only is supplied, more than one transformer is rarely located in the same manhole; but where the secondary distribution is three-phase it is the practise to locate three transformers in the manhole. In no case on our system has it been found necessary to provide ventilation for manholes, even though water-tight covers are used.

When the subway system was first installed, the question of ventilation was considered, the plan being to run riser pipes to nearby iron trolley poles, or to provide a suitable design of hitching post with double draft pipes. It might be interesting to note that in the first alternating-current system installed in San Francisco the transformers were water-cooled, a special circulating system being built when the conduit system was laid. This feature has, however, been entirely abandoned.

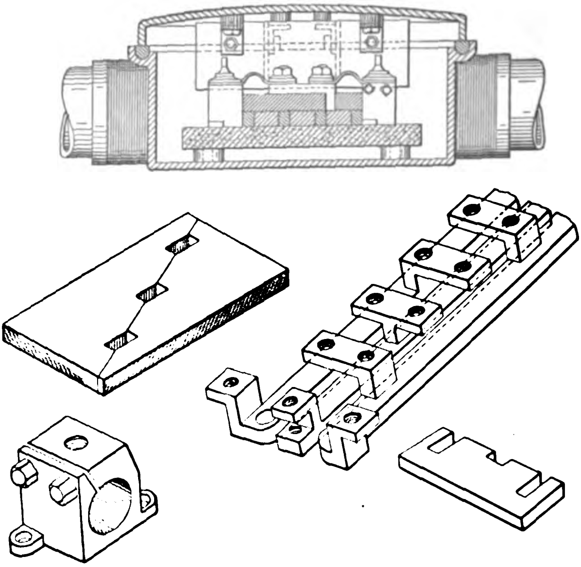


Fig. 5a.—250-Volt 3-Phase Junction Box, Detail of Bus and Terminal

Transformers were provided with a relief plug, consisting of a thin copper diaphragm which was supposed to break if abnormal pressure developed in the transformers. Past practice has shown the relief plug more troublesome than necessary; continual corrosion of the copper diaphragm admitted moisture. Recent tests have shown that the explosions within the case are not relieved by the diaphragm. With the number of transformers in service, troubles of an explosive nature have been so rare as not to be worthy of mention.

Operating Features

Each feeder is protected at the station with an oil switch equipped with an overload definite time limit relay, no fuses being used except on the transformers. Disconnecting switches are so installed that the regulators can be entirely cut out of service with only a momentary flicker.

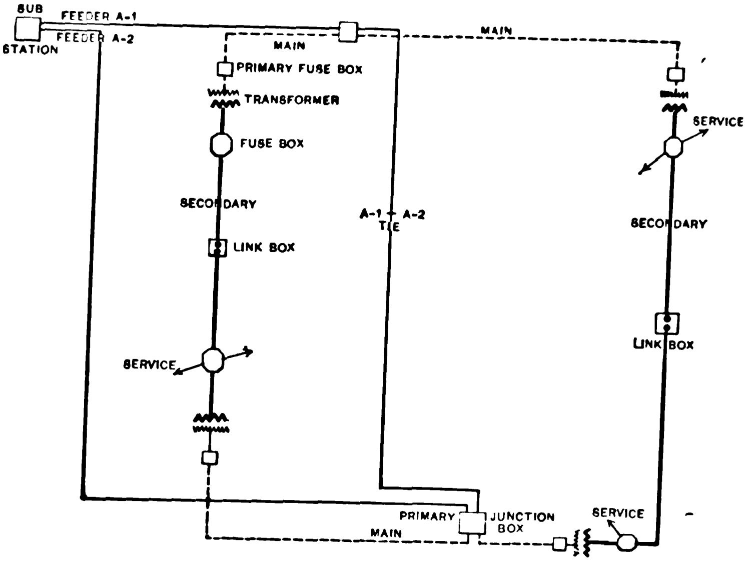


Fig. 6.—Diagrammatic Arrangement of A-C. Distribution System

Feeders in the underground territories for the most part are run entirely underground, taking different routes to the several centers of distribution. In some cases the lines are overhead from the station to the boundary of the underground district, in which case suitable potheads are installed on the riser of the cable terminal. Disconnecting switches are installed on the riser pole to provide a quick means for either operation or testing.

To give an idea of typical conditions: three feeders supply a territory approximately one mile (1.6 km.) by one-quarter mile (0.4 km.), in which there is a load of 3,000 kw. Fig. 6 shows a typical distribution arrangement. The feeders end in junction boxes, from which the mains radiate. A tie cable connects the two junction boxes. The transformer secondary leads are fused in the secondary junction boxes. Both mains and services radiating from the secondary junction box are likewise fused.

Secondary junction boxes are installed only at points where transformers feed the network and where mains intersect. Where secondary junction boxes are not installed the service cable is tapped directly to the main with a suitable fuse provided on the consumer's premises. Link boxes are located at suitable points in the secondary network, through which the mains may be tied together.

It will be noted from Fig. 6 that any section of the distributing system can be separated by means of the junction boxes, thus providing a means for operation and inspection of the system and isolation of the affected part with a minimum interruption to the other parts.

No cable splicing is done on live cables where the potential exceeds 750 volts, although the links in all boxes are operated alive. In operating the box shown in Fig. 1A sheet rubber barriers are placed between opposite poles, the operator using rubber gloves and a " hot tool " in the form of wood pliers. The links can be opened and closed with current on the line not to exceed 50 amperes. With 200 in service they have been successfully operated for over four years without an accident.

The same operating conditions apply to the 4,000 volt boxes shown in Fig. 2, except that the rubber barriers are not necessary by reason of the porcelain compartments. A sheet of fibre covers the section of the box which is not being operated. These boxes have been operated on a line current of 75 amperes with no difficulty. Very satisfactory results have been obtained from the 25 boxes of this type in service.

Certain operating difficulties were encountered after the first automatic regulators were installed. It was attempted to tie together two different feeders fed from the same bus bar. The results were disastrous to the box. The accident was attributed to the fact that the feeder regulators were not set at the same point and there was therefore a large interchange of current momentarily taking place. The regulators were then set at neutral point, but instead of endeavoring to tie the feeders together through the medium of a junction box, a phasing transformer was connected across the gap. The results of this test showed conclusively that the tie could not be made even under these conditions. A further analysis demonstrated that a violent surge takes place when the links are closed, due to the capacity of the cables in series with the high reactance of the induction regulators. This difficulty was obviated by equipping the feeders with a disconnecting switch located at the station, by means of which the regulators on the feeders can be disconnected from the circuit, which operation is performed when it is desired to tie the feeders together.

The oil fuse box shown in Fig. 3 is mounted in a horizontal position. The fuse is connected across the terminals of the holder. The box is filled with light mineral seal oil which aids the operator in noting the condition of the fuse. The same type of " hot plier " is used. With 400 of these boxes in service, extending over a period of five years, only three failures have been recorded; one box being entirely exploded, and in the two other cases the covers being shattered. In one of these cases the fault was directly traceable to moisture that had entered the oil in shipment. These boxes have repeatedly cleared short circuits on transformers with no injury to the box. Relief valves of the same type as those discussed under the heading " Transformers " were proposed for use on these boxes, but test and experience have proved that they are unnecessary. All boxes are mounted on pipe supports about three inches (7.6 cm.) away from the side walls of the manhole. This allows the easy passage of through cables.

The secondary boxes are operated in a manner similar to the primary boxes, sheet rubber barriers being inserted to prevent the links or fuses from falling across adjacent terminals. A hot wrench with a wood handle is used in place of the pliers. The operation is so simple that little explanation is needed. It might be stated that there are approximately 1,000 of these boxes in service.

The neutral of all the secondary system is grounded, both at the manhole to ground plates and cable sheaths, and on the consumers' premises. However, in no case is the same wire used as a neutral for both primary and secondary systems.

As an alternating-current feeder supplies a load of approximately 1,000 kw., a larger number of consumers would be affected if the feeder were out of commission than would be the case with a direct-current feeder. In the event of trouble developing on on a direct-current feeder the voltage drops, but the consumer suffers no interruption of service. Much greater care must therefore be exercised in the operation of the alternating-current system than in the direct-current system. When extensions to the primary system are made, the load must be transferred on the secondary side in order to shut down the primary cable. (See Fig. 6.) This operation is not necessary on the direct-current system.

No fuses are used in the primary system, except on transformers, as practice has demonstrated that fusing of mains is unsatisfactory and further complicates the operation of the system. In two cities where we are supplying loads of 3,000 kw. in a small congested district no trouble has been experienced on the general system during three years of operation, in which time faults have occurred on the secondary system, and in transformers, which were successfully cleared by the secondary fuses and the transformer oil fuses.

Conclusions

Our experience with an alternating-current system, the load on which aggregates 12,000 kw., has demonstrated that the system can be successfully operated. The design and operation of an underground alternating-current system, as compared with a direct-current system, should present no serious difficulties—provided, however, that suitable sectionalizing devices are obtained for use on the high-voltage parts of the system.

Safety to the workmen, and continuity of service, demand the use of more reliable apparatus on an alternating-current system than is required on a direct-current system.

Questions of comparative cost between the alternating and direct-current systems have been purposely omitted, as the price of real estate, substations, and equipment will greatly affect the investment. The additional cost of sectionalizing devices for the alternating-current underground system is small as compared with the costs of the direct-current system. Load, service, and competitive conditions will be important factors in the choice of the system.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16–20, 1912.

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(Subject to final revision for the Transactions.)

AUTOMATIC PRIVATE BRANCH EXCHANGE DEVELOPMENT IN SAN FRANCISCO

BY GERALD DEAKIN

A few years ago, the majority, in fact a very large majority, of those interested in the technical aspect of the telephone, considered what is now well known as the automatic telephone, impracticable for central office service, even in single office districts. This erroneous idea has long since been dispelled by the installation and subsequent satisfactory operation of numerous extensive automatic systems, many of which each include a number of large central offices. Following the satisfactory development of the central office, it was soon realized that a great saving could be made in the exterior cable plant, if small unattended or partially attended sub-offices, as they are now called, could be built, to give efficient and economical service. It will suffice here to say that the experiment was tried with the result that the sub-office is now considered a necessary adjunct to the automatic central office. The purpose of this paper, is to show that the unattended sub-office is by no means the limit of sub-division and that such sub-division has now been successfully extended to include two somewhat distinct types of private branch exchanges, one adapted to meet the requirements of apartment houses and family hotels and the other the more exacting requirements of all classes of commercial organizations and business houses. The most noticeable difference between the two is that the former is arranged, apart from some minor features, to give "in" and "out" exchange service only, while the latter is arranged to give "local inter-communication" as well. The automatic system has not as yet been applied to the larger commercial hotels where the total annual cost of the equipment involved is great in comparison with the average revenue derived per telephone. At the present time, the first cost of automatic apparatus prohibits its general use in such places.

In the following pages, an attempt has been made to describe briefly, the apartment house and the commercial automatic private branch exchange systems, as developed by the Bay Cities Home Telephone Company, for general use in San Francisco, and the materials and apparatus involved; also their advantages and disadvantages, and their first and annual costs, compared with the well known manually operated private exchange.

APARTMENT HOUSE AUTOMATIC PRIVATE BRANCH EXCHANGE

The first exchange of this character installed in San Francisco was placed in service December 12, 1910. Since that time, 24 additional installations have been made. These exchanges now serve a total of 727 stations, an average of approximately 29 stations per exchange. The maximum installation is 70 stations and the minimum 11 stations. Each installation includes a small portable automatic switchboard and storage battery. The former contains the call forwarding and receiving apparatus and a meter for each apartment. The switchboards are installed adjacent to the terminus of the house wiring. The majority of installations have been made in unfinished basements with concrete floors, and in these locations the switchboards have given very satisfactory service. Other switchboards have been placed in small closets and in other locations having no particular value for other purposes. The apartment telephones differ in no way from the usual main line automatic sets. The public telephones, installed in some of the larger apartment houses, consist of similar sets equipped with coin machines, Fig. 1. An instrument called the "house telephone," Fig. 2, installed in or adjacent to the office, landlord's or janitor's quarters, as the case may be affords a means of intercommunication between each apartment and the head of the house. Vestibule and tradesmen's entrance telephones are included in many of the installations. Each installation made in a family hotel, also includes a small receiving cabinet, Fig. 3, and a service meter cabinet, both of which are placed in the office of the hotel. The former provides a means whereby the public may call guests through the office in case the room number is not known. The latter places the meters under the supervision of the clerk and permits the rapid settling of accounts in case of transient guests.

The distinctive features of the apartment house automatic private branch exchange may be briefly outlined as follows:

1. Affords a comprehensive telephone system in which a branch exchange operator or attendant is not required.
2. Affords each apartment metered and direct " out " exchange service.
3. Affords each apartment direct " in " exchange service.
4. Affords each apartment 24-hour service.
5. Affords each apartment the equivalent of main line service.
6. Affords each apartment secret service.
7. Affords each apartment a means of intercommunication with the head of the house.
8. Affords each station direct service from vestibule and tradesmen's entrance.
9. Affords automatic pay station service for the public.
10. The switchboard may be placed in any convenient and reasonably dry location.

DESCRIPTION OF OPERATION

Outgoing Exchange Calls. A subscriber, when making an exchange call from an apartment, removes receiver from hookswitch and listens for the " busy tone," which if heard, indicates that all trunks are in use. Failing to get the busy tone, the subscriber proceeds to call the number of station wanted by turning the dial in a manner[1] now well known in automatic telephone practice The call bell at the distant station rings intermittently until the party called answers or until the party calling hangs up in case the party called does not answer. When the distant station answers, the meter associated with the calling line operates, and registers one call; under no other condition will the meter operate. Should the station called be busy, the usual tone indicating this will be heard. When the calling subscriber hangs up, the connection is released. Calls to information, complaint or other departments of the telephone company, are not registered.

Call to House Telephone. To make a call from an apartment to the house telephone, the subscriber calls a predetermined number, such as C–05, the circuit conditions thus and only thus established automatically transfers the out-trunk from connection with the central office to connection with the corresponding answering button on the house telephone, which telephone is equipped with a key of the well known inter-communicating type, wlth a button for each working out-trunk. Adjacent to each button, is a small signal lamp. Should the call happen to be made on out-trunk number 2, the lamp opposite button number 2 will light, and at the same time a buzzer will sound. The proprietor, manager or janitor, as the case may be, in answering depresses the button opposite the lamp burning, thereby extinguishing the lamp and causing the audible signal to cease. The connection is now established. The circuit of the house set is such that it can be connected to an out-trunk only when the associated lamp burns. In this way, secrecy is secured. It should be noted that no central office apparatus is involved or tied up in the completed connection. The subscriber's meter does not register these calls.

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[1] Sée W. L. Campbell on " A Modern Automatic Telephone Apparatus, TRANSACTIONS A. I. E. E., 1910, p. 55

Incoming Exchange Calls. In the directory listing of apartment house automatic systems, the telephone number of each apartment is divided into two parts, as for example, C5517—43 The first part of this number, namely C5517, pertains to the apartment house and the second part, namely 43, to the individual apartment, and where possible, coincides with the apartment number. In calling the apartment, whose telephone number is that just given, the subscriber calls the first five-digits in the usual manner, and in so doing automatically selects an idle in-trunk to the apartment house switchboard, there terminating the partially completed connection upon the associated connector. The last two digits when called, cause the connector to select and ring the apartment whose telephone number is 43. For the information of the public, the telephone company maintains a record of names of the occupants of all apartments. In this manner, the information bureau of the telephone company removes the burden of inquiries from the management of the apartment house.

Calls to patrons living in family hotels, may be made as above described where the full telephone number is known or can be ascertained. When direct calling is not convenient, the call may be made through the receiving cabinet, the telephone number of which is always listed. A call of this nature is indicated at the receiving cabinet by the burning of the lamp associated with the in-trunk involved in the connection. The attendant, in answering throws the associated answering key and is placed in direct communication with the calling subscriber, and after ascertaining the name of the party wanted, extends the call automatically to the proper station. When the called party responds, the answering key is restored to its normal position. This removes the attendant from any further control of the connection, which is released automatically when the calling subscriber hangs up. The attendant cannot listen on any completed connection, whether made direct or through the cabinet.

Incoming Calls from Local Telephones. The house, vestibule or tradesmen's telephones are not adapted to originate or receive exchange calls. Local calls to various apartments, however, may be made by calling on the dial, the two digits representing the number of the apartment wanted.

Pay Station Calls. All exchange calls to and from the pay station telephone may be received and made in the usual manner provided that on outgoing calls a coin is deposited before or after calling, depending upon the character of the coin machine. Both prepayment and postpayment automatic machines are in use.

Commercial Automatic Private Branch Exchange

The first commercial private branch exchange of the automatic type installed in San Francisco, was placed in service May 27, 1911. Since that time 10 additional installations have been made. These 11 exchanges serve a total of 420 stations, an average of approximately 38 stations per exchange. The largest installation is 75 stations and the smallest nine stations. Each installation includes a portable automatic switchboard and storage battery similar to those placed in apartment houses. The switchboards, however, contain apparatus for local intercommunication as well as for in and out exchange service. A receiving cabinet, Fig. 4, adapted to receive and distribute incoming calls, which for one reason or another, are not made direct, is a necessary part of every commercial installation.

The salient features of the commercial automatic private branch exchange, may be briefly stated as follows:

1. Eliminates all operators and switchboard attendants, except those required for strictly information purposes, thus effecting a direct saving in operator hire either by eliminating the operator or by assigning her other duties.
2. Affords rapid and direct intercommunication between all local stations.
3. Affords direct " in " exchange service.
4. Affords direct and metered " out " exchange service.
5. The full value of the system is available 24 hours each day and every day in the year.
6. Instantaneous disconnection upon hanging up, thus permitting the making of a number of successive calls in the shortest possible time.

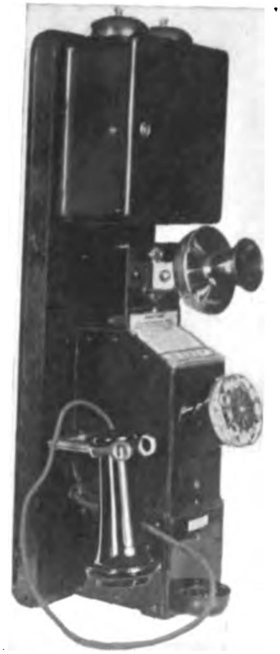
7. Each station is afforded the equivalent of direct main line service.
8. All connections, local and otherwise, are strictly secret.
9. Eliminates the necessity of other means of rapid intercommunication, now so common with manually operated private branch exchange switchboards.
10. Combines rapid intercommunication with regular telephone exchange service.
11. Automatic restriction of any station, to local service, thus preventing the abuse of outgoing exchange service.
12. But two wires are required per station, thus permitting the redistribution of telephones at a minimum cost. This point should not be overlooked when comparing the operating costs and flexibility of the automatic system with other systems requiring key buttons and other apparatus, necessitating the running of many wires to each station.
13. There is no limit to the size of any private exchange.
14. Any number of private exchanges may be interconnected and operated as one system, all, part, or none of which may have exchange service.

DESCRIPTION OF OPERATION

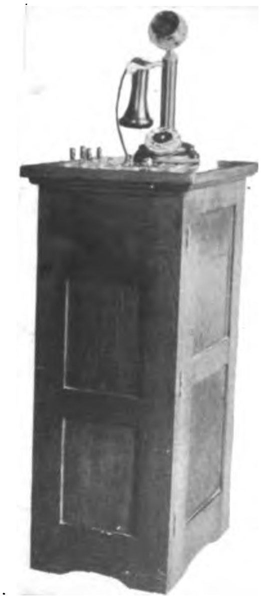
Local Calls. In a commercial private exchange of a capacity not greater than 90 stations, any station may call any other station by calling on the dial, the two digits representing the number of the station wanted. Thus a station would call the digits 2 and 5 to effect a connection with station 25. The bell at the station called, rings until the call is answered or until the calling party hangs up in case the call is not answered. Should all "mechanical operators" or the called station be busy, the usual busy tone will be heard. A connection is released when the calling subscriber hangs up. Where the capacity of a private exchange system exceeds 90 stations, three digits must of necessity be called in place of two.

Outgoing Exchange Calls. To make an exchange call, the private branch exchange subscriber first calls the digit "0" to effect a connection with an idle out-trunk, and then the number listed in the directory. Should all out-trunks be busy, the busy tone will be heard as soon as the digit "0" is called. Each completed outgoing exchange call is registered upon a meter located in the central office and associated with the out-trunk involved in the connection. Calls to the telephone company's information and other departments, are not registered. Any local station may be restricted to local calling, that is, the station may not originate exchange calls, although it may receive exchange calls.

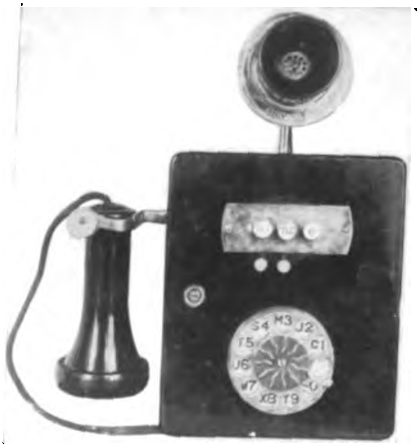
Incoming Exchange Calls. Incoming exchange calls may be made direct to any local station. To facilitate this, each local station, or such of them as the public may have occasion to call



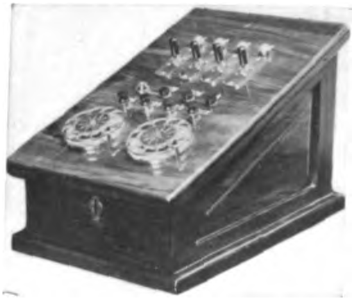
[DEAKIN]
FIG. 1.–PUBLIC TELEPHONE Equipped with 3-slot Prepayment Coin Machine



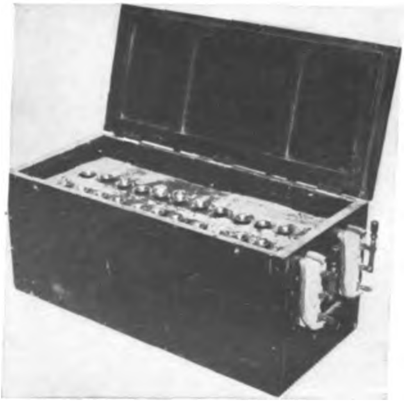
[DEAKIN]
FIG. 4.—COMMERCIAL EXCHANGE RECEIVING CABINET



[DEAKIN]
FIG. 2.—HOUSE TELEPHONE FOR APARTMENT HOUSE SYSTEMS



[DEAKIN]
FIG. 3.—HOTEL RECEIVING CABINET



[DEAKIN]
FIG. 9.—PORTABLE STORAGE BATTERY

are listed in the directory. The directory number as for apartment house systems, must consist of two parts, the first part indicating the private exchange as a whole, and the second part the local station number. Any call, which from the lack of information or otherwise, cannot be made direct to the proper local station, may be directed to the receiving cabinet, and when so directed causes a lamp associated with the particular incoming trunk involved in the connection, to light. The operator, when answering, throws an associated answering key and obtains such information from the calling subscriber as may be necessary, after which the call is automatically extended to the proper station. The answering key remains thrown during this operation and in fact until the operator has finished with the call. Should the operator find it necessary to transfer the call, she may release the ocal connection and then reëstablish it with another station. When the proper party has been located, the operator restores the answering key to its normal position, which places the calling and called subscribers in direct communication with each other and makes further supervision on her part unnecessary. The connection releases when the calling subscriber hangs up.

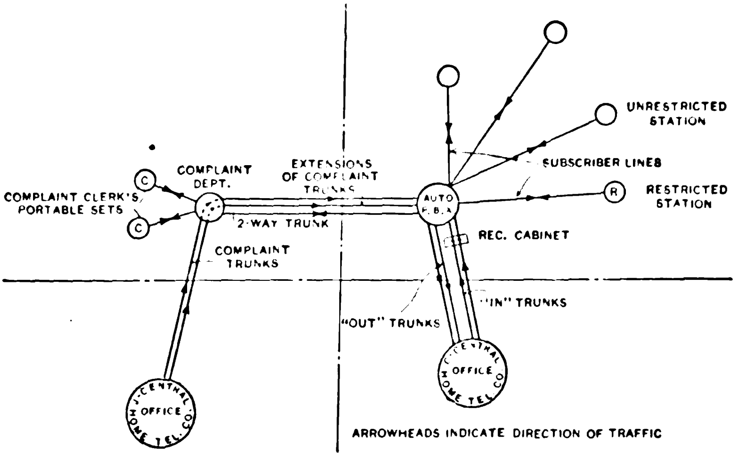

C
C
COMPLAINT CLERK'S PORTABLE SETS
COMPLAINT DEPT.
EXTENSIONS OF COMPLAINT TRUNKS
2-WAY TRUNK
COMPLAINT TRUNKS
AUTO P. B. X
UNRESTRICTED STATION
SUBSCRIBER LINES
R
RESTRICTED STATION
REC. CABINET
"IN" TRUNKS
"OUT" TRUNKS
CENTRAL OFFICE HOME TEL. CO.
CENTRAL OFFICE HOME TEL. CO.
ARROWHEADS INDICATE DIRECTION OF TRAFFIC

FIG. 5.—LINE AND TRUNK DIAGRAM OF INSTALLATION NO. 15

Some Special Applications. The ease with which the automatic system may be adapted to meet special conditions, is indicated to some extent by the arrangements made to handle calls in installation 15. A line and trunk diagram of this installation, appears in Fig. 5. The system comprises an automatic switchboard, a receiving cabinet and a plurality of special portable sets located in the complaint department, approximately one mile from the central offices. The complaint department and the general offices have different numbers, and so far as the public is concerned, are separate exchanges. Prior to the installation of this system, experience had shown that many complaints were directed to the complaint department which should have been directed to some department in the general offices. To handle such calls, the automatic equipment has been adapted to permit any misdirected call to be extended through the automatic private exchange switchboard to the proper department, the complaint clerks are merely required to call the two digits representing the station wanted. Similarly any call directed to the receiving cabinet, may be transferred to the complaint department.

In another installation, four closely associated companies are served by the same switchboard. Each company has a separately listed receiving cabinet, but all make use of a common set of in-and out-trunks. Local intercommunication between the four companies is given on a two number basis.

SWITCHBOARD EQUIPMENT

The individual pieces of automatic apparatus represent the latest development in switches of the Strowger and Keith types. A description of these switches as applied to central and sub-offices, will be found in a paper[2] by Mr. W. L. Campbell. To avoid repetition, mention is made here only of those features and adaptations which have especial reference to the automatic private exchange switchboard. To meet all demands, three sizes of switchboards have been developed with capacity for 25, 50 and 100 lines, respectively. The 25-line switchboard, Figs. 6A, 6B, 6C and 6D, is 21 in (51.3 cm.) square and 3 ft. 9 in. (1.13 m.) high. The 50-line switchboard, Figs 7A and 7B is 21 in. (51.3 cm.) square and 5 ft. 7 in. (1.6 m.) high. The 100-line switchboard, Figs. 8A and 8B, is 2 feet 8 in. (81 cm.) wide, 21 in. (51.3 cm. deep and 6 ft. 9 in. (2 m.) high. Each switchboard is a complete unit by itself and contains all apparatus necessary for its proper operation. The cabinets are fire-proof, dust-proof and as nearly moisture-proof as possible. It has been found that variations in temperature, at least those met with in San Francisco, do not materially affect the operation of the switches. Dust and appreciable moisture, however, make their presence known at once. The charging circuit of some of the larger storage batteries, include one or more small resistance lamps. These, when placed in the cabinet, have proved effective in expelling moisture.

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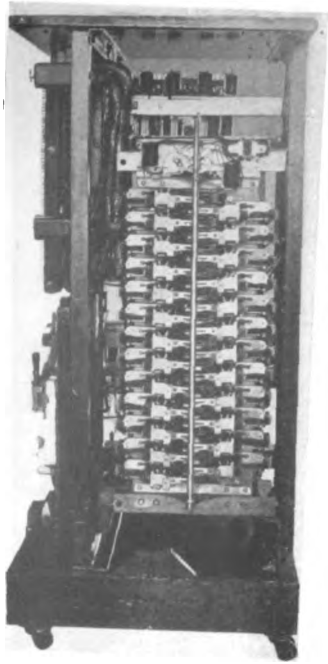
[2] A. I. E. E. TRANSACTIONS, 1910, p. 55.

Each apartment house switchboard is equipped with a sufficient number of Keith line switches and service meters to provide one of each for each apartment. There is also provided a connector of the Strowger type for each in-trunk and for the house telephone. In the commercial switchboards, a line switch without service meter, is provided for each station, a connector for each in-trunk and a sufficient number of " mechanical operators " to handle the local and out-trunk traffic. The relative locations of all equipment will be seen at a glance in the figures previously referred to. A 25-line board will accommodate eight large switches, a 50-line board 12 and a 100-line board 18.

The line switch banks in the apartment house switchboards figures 6A, 7A and 8A, are connected to two-wire out-trunks, which trunks terminate at the central office on primary line switches, and these in turn on secondary line switches and finally on first selectors. The act of removing the receiver from the hookswitch, causes all three line switches to plunge in simultaneously. Each out-trunk circuit, includes a train of relays which relays, under certain conditions established as before mentioned, only when a certain number is called, are adapted to automatically disconnect the private exchange end of the out-trunk from connection with the central office apparatus and in place thereof connect it to the house telephone, Fig. 2. All line switch banks are multipled and each bank has capacity for 10 out-trunks, that is, each line switch has access to this number of trunks. Under ordinary conditions, one master switch controlling access to 10 trunks, is sufficient. Should, however, the traffic be heavy enough in the larger boards to require more than 10 trunks, additional master switches may be added so as to provide as many as 10 out-trunks for each 25 line switches. The trunk connectors on the reverse side of the switchboard, Fig. 7B, are directly connected to two wire in-trunks, which trunks at the central office, appear in a multiple before the proper selectors. All apartment lines are multipled through the connector banks.

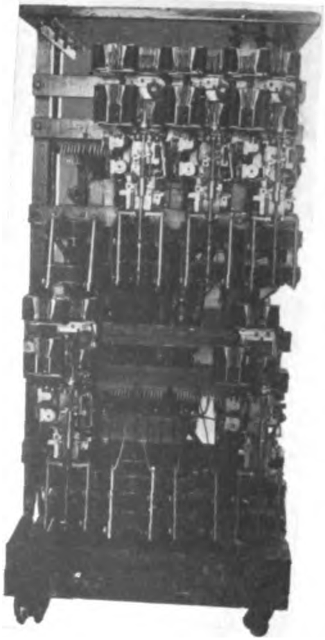
In commercial private exchange switchboards, the line switch banks, Fig. 6A, are wired to the " mechanical operators." The " mechanical operator," as it has been called for the lack of a better name, is a switch in which the functions of the selector and connector are combined. This switch operates as a connector in establishing two number local connections. It supplies the necessary current for central energy speech transmission and automatically rings the call bell at the called station. When the digit " 0 " or other proper predetermined number is called, the switch is automatically converted into a selector and rotates automatically until an idle out-trunk is selected, after which it affords a clean pair of wires free from all bridged relays and other coils, for the transmission of the subsequent impulses. By a very simple change in line switch bank wiring, the switch restricts the local thus changed to local service. Should an exchange connection be attempted by a restricted station, the switch will release when the trunk " level " is reached.

The development of the mechanical operator has greatly simplified the design of the commercial private exchange, in fact it has made the commercial private exchange possible, for without it, not only would the cost and size of the switchboard be increased, but local calling on two digits, a valuable asset of the present, switchboard, would not be possible. The banks of the mechanical operators include a multiple of all local lines as well as a multiple of the out-trunks, which trunks are usually connected to the " 0 " level. The out-trunks terminate in the central office on line switches, as do those from apartment house installations. The in-trunks from the central office pass through a normally closed circuit in the receiving cabinet, to the connectors, the banks of which are multipled with those of the mechanical operators. The in-trunk connectors may be provided with a "back release " whereby any connector may be released by either the calling or called subscriber. Such a release circuit makes it possible to transfer a call from one local station to another without requiring the calling subscriber to disconnect. The calling subscriber is merely required to call the two digit number of the second station, after the station first called has hung up. This latter act causes the connector in the private exchange switchboard, to release, the remainder of the connection in the central office, however, is not released until the calling subscriber hangs up. The receiving cabinet, Fig. 4, in each exchange is assigned some particular number, which when called through a particular connector, results in the lighting of the lamp associated with that connector. The function of the receiving cabinet circuit is to release the connector from the connection with the receiving cabinet contacts and cause it to select as directed, the bank con-



[DEAKIN]

FIG. 6A.—FRONT ELEVATION OF 25-LINE SWITCHBOARD Door Removed, Showing Line Switches



[DEAKIN]

FIG. 6B.—REAR ELEVATION OF 25-LINE SWITCHBOARD Doors Removed, Showing "Mechanical Operators," Connectors and Banks

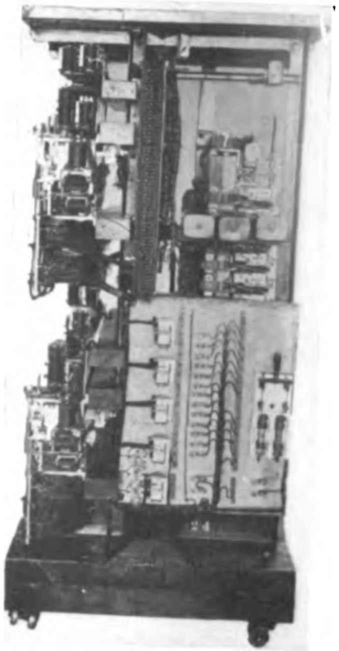


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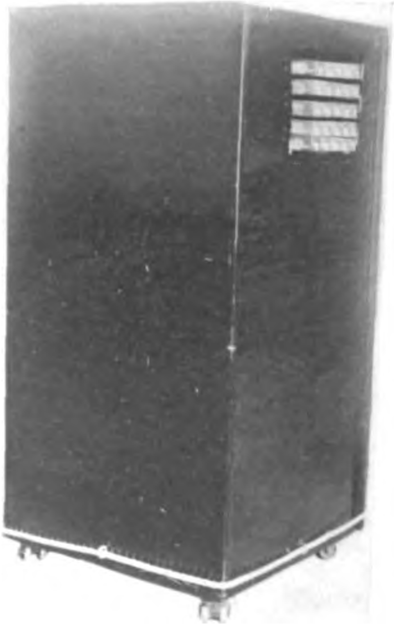
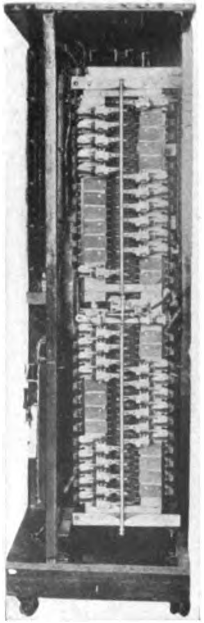
FIG. 6C.—SIDE ELEVATION OF 25-LINE SWITCHBOARD Doors Removed, Showing Power Panel, Terminal Strips and Miscellaneous Relays.



[DEAKIN]

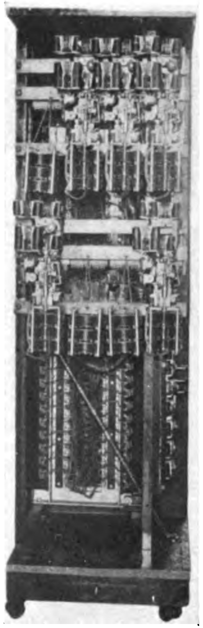
FIG. 6D.—ELEVATION OF 25-LINE SWITCHBOARD Doors in Position. Meters Shown Protected by a Glass Plate



[DEAKIN]

Fig. 7a.—Front Elevation of 50-Line Switchboard

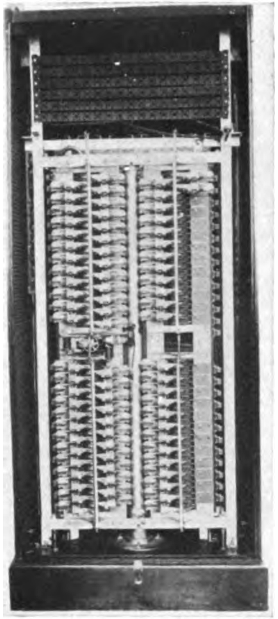
Doors Removed, Showing a Partial Equipment of Line Switches



[DEAKIN]

Fig. 7b.—Rear Elevation of 50-Line Switchboard

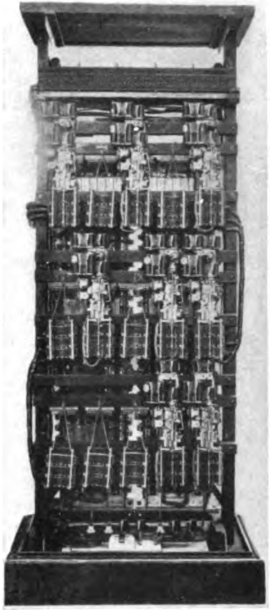
Doors Removed, Showing Connectors and Banks



[DEAKIN]

Fig. 8a.—Front Elevation of 100-Line Switchboard

One Door Removed, Showing Line Switches, Master Switch and Service Meter Strips in Position



[DEAKIN]

Fig. 8b.—Rear Elevation of 100-line Commercial Switchboard

Doors Removed, Showing the "Mechanical Operators," Connectors and Switch Banks in Position

tacts of the desired station, leaving the circuit conditions, after the receiving operator has cut out, the same as if the call had been made direct from one station to the other. The noticeable feature about the receiving cabinet is its simplicity. No cords, plugs or jacks are required, merely two keys and a lamp for each in-trunk.

One hundred lines is by no means the limit of the automatic private exchange. Beyond this limit, however, the use of three or more digits is necessary. The switchboard cabinets have been designed with a view of permitting them to be lined up and operated as one switchboard, a condition always to be met in office buildings.

Each switchboard is wired and arranged for over-flow meters installed from time to time, to determine the sufficiency of the facilities provided. Three meters are required for commercial installations, one adapted to record the attempts made to call when all mechanical operators are busy, another the attempts made to call when all out-trunks are busy and another the attempts made to call when all in-trunks are busy. Meters are also provided to register the total in, out and local calls. Commercially, the ability to take such readings, is of great value to the telephone company as it affords something definite to offer the subscriber as an argument why inadequate facilities should be increased. Each board is assembled and tested before leaving the shop so that the labor required to install one of them is not much greater than that required to install the corresponding manual switchboard.

CURRENT SUPPLY AND SUPERVISION

The source of direct current required for the operation of an automatic private exchange switchboard and for central energy speech transmission, must afford a fairly uniform and constant potential, a condition not so essential for the proper operation of a manually operated private exchange switchboard. It must also be capable of supplying comparatively large currents for short intervals, for the intermittent operation of the motor and release magnets, some of which require as much as an ampere and a half. It is quite possible that the simultaneous operation of a number of switches might result in a call for five or six amperes, which in telephone private exchange work, is considerable. These currents, however, are required for periods on the order of a second and therefore, do not involve much power. Intermittent currents of this nature tend to reduce the potential of the supply at the switchboard bus bars and make the speech transmission circuits noisy, and therefore must be taken into consideration as a factor in determining the character of the current supply. It has been found that automatic switches can be adjusted to operate positively within a range of potential varying from approximately 45 to 55 volts, providing that all switches are adjusted at normal potential of 48 to 50 volts.

The foregoing requirements have all been satisfactorily met by installing small portable storage batteries within a few feet of each switchboard. These batteries each consist of 23 elements contained in rubber jars, the whole mounted in a substantial oak carrying case, with the intervening spaces filled with an insulating and acid-proof compound so that should a cell become cracked, the electrolyte will not escape. Such a battery is shown in Fig. 9. The case is made nearly fume-proof, so as to permit the battery to be placed, without objection, in an office or other occupied quarter. Each battery is given its initial charge in the warehouse or shop, which, together with the fact that the terminals are brought out to end cell switches, permits the immediate installation of the battery upon delivery. The end cell switches are used chiefly as a means of obtaining the normal potential when adjusting switches. Intermittent charging of a storage battery results in high and low potential values. To eliminate such variation as far as possible, the batteries are floated on approximately constant currents, which currents are adjusted to

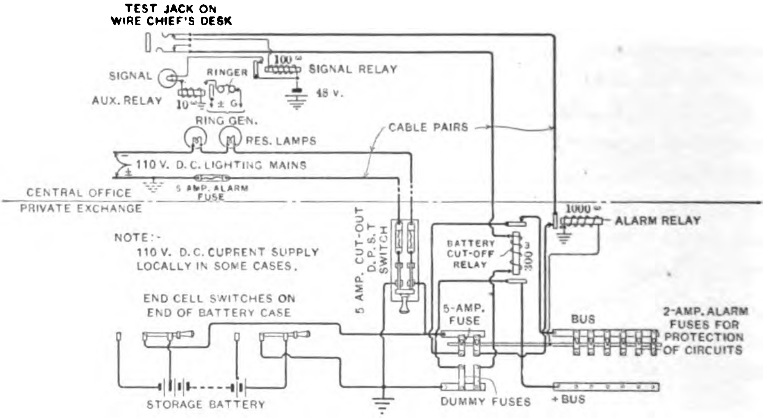


FIG. 10.—CURRENT SUPPLY AND SIGNAL CIRCUITS

meet the 24-hour requirements of their respective installations. Providing the floating or charging current is made sufficient, the smallest size of commercial battery can be made to handle the largest exchange. From the standpoint of economy, however, the capacity of the battery should be such as to permit it to handle the peak loads of the exchange, without requiring an increase in the normal day and night floating currents, in case the two are not the same, to prevent a serious drop in potential. From the information available at the time the first installations were made, it was calculated that economical results could be obtained by the use of batteries having the following ampere hour capacity. The results obtained to date have been very satisfactory and so far have not warranted other assumptions.

Total in, out and local calls per working day.	Capacity of Battery.
400	6 ampere hours
800	12 " "
1600	24 " "
2400	36 " "

The foregoing figures allow for contingencies in the way of abnormal traffic and trouble.

The current supply and signal circuits of a typical installation are shown in Fig. 10. It will be seen that the storage battery receives its charging current from the city 110 volt direct current lighting mains, which current may be supplied locally, or as is preferable, over an idle cable pair from the nearest central office. When supplied in this latter manner, the current may be regulated with ease. The circuit affords the wire chief at the central office, complete supervision of the power supply and a ready means of obtaining voltage readings. All important pieces or groups of pieces of automatic apparatus on each private branch switchboard, are served by separate fuses of the alarm type. The fuses are of low capacity, so that should a switch stick, or otherwise permanently close a low resistance circuit through some motor magnet, or create a short circuit, the corresponding fuse will blow and give the alarm at the central office. The wire chief, by the proper manipulation of his testing circuit, not shown in the figure, may remove the current supply from the switchboard and in this way often release a sticking switch. Furthermore, the guard relay at the central office is adjusted to operate should the difference in potential between the private exchange and central office batteries exceed three volts.

The curves plotted in Fig. 11 show the potential variation at the switchboard terminals, of two six-ampere hour batteries, or a period of seven months. The average continuous charging current in each case was approximately 0.1 of an ampere. It will be seen that in no case did the potential vary beyond the limits previously given. The voltage readings of all batteries are taken and recorded at 8 o'clock every morning and the curves just mentioned, are plotted from these readings. These curves may be applied to all apartment houses without serious error and to other installations where the volume of daily traffic is more or less constant. The traffic, however, in most commercial installations, originates almost entirely between the hours of eight in the morning and six in the evening, and on working days only.

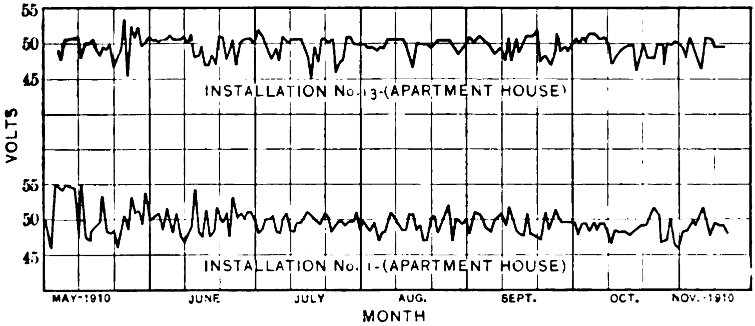


FIG. 11.—POTENTIAL VARIATIONS OF TWO SMALL (6 amp-hr.) STORAGE BATTERIES
Average Charging or Floating Current, 0.1 Ampere

At other times, the traffic is almost negligible. This condition is very clearly illustrated by the potential curves, Fig. 13, which apply to a 24-ampere-hour battery serving a large commercial installation, handling approximately 1250 calls of all classes per working day. In this particular case, the best results were obtained by adjusting the continuous charging current during working hours, to from 0.5 to 0.8 of an ampere and during nights and holidays to from 0.1 to 0.3 of an ampere. Both these and the following curves are plotted from readings taken at 15-minute intervals. The potential curves shown in Fig. 12 apply to a storage battery installed to take care of an automatic switchboard in a large newspaper establishment. Here the best results were obtained by floating the battery continuously on a current of approximately 0.35 of an ampere. This is one of the compara-

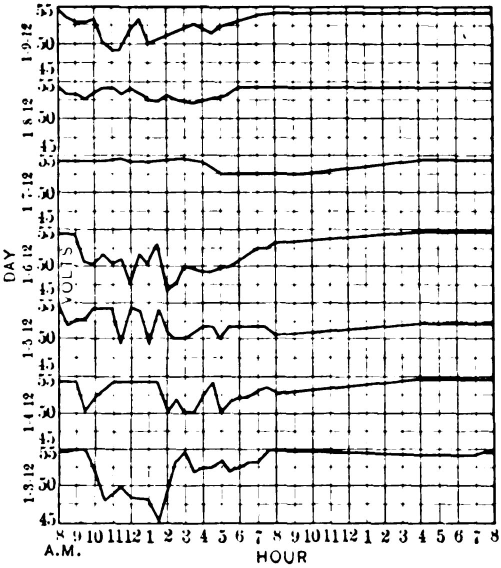


Fig. 12.—Potential Variations of a 12-amp-hr. Storage Battery Installation No. 21; Charging Current 0.35 Ampere

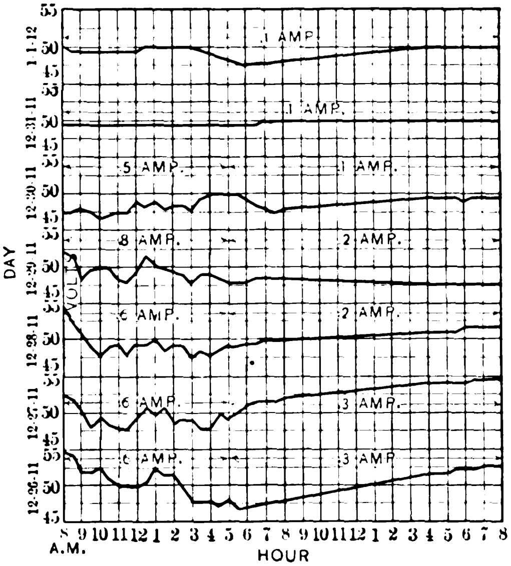


Fig. 13.—Potential Variations of a 24-amp-hr. Storage Battery Installation No. 15; Charging Current Indicated

tively few commercial installations in which the traffic is considerable during the night hours.

The routine adhered to in maintaining these small and isolated batteries, is to record their voltage readings at the central office daily and to take the specific gravity of the pilot cell once in every two weeks and the specific gravity of each cell once in every two months. This plan does not involve any great amount of labor, but it effectively prevents the condition of any battery becoming serious, without ample warning. The particular battery used in the installation handling the heaviest traffic, has been in service five years. Prior to its installation in its present location, it was used by the construction company, for a similar purpose during the building of the independent telephone plant in San Francisco.

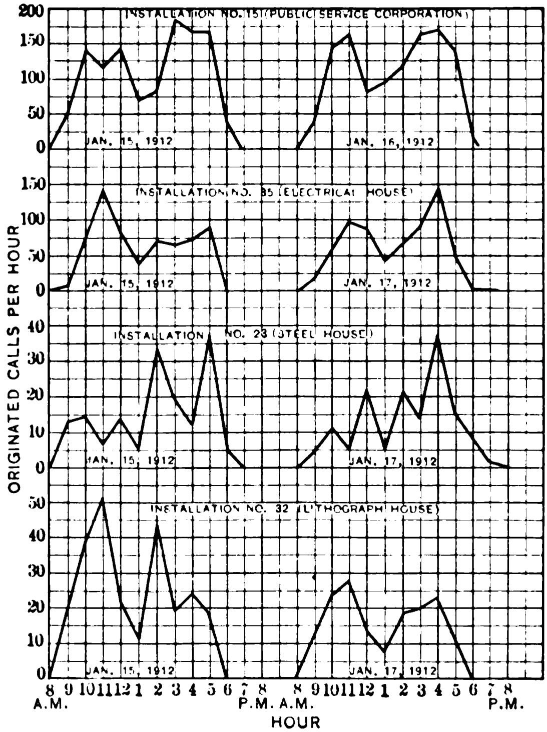


FIG. 14A.—HOURLY TRAFFIC—ORIGINATED CALLS

SOME TRAFFIC DATA

Local calling, in the commercial exchanges, affords some interesting data regarding the capacity of the mechanical operators to handle a heavy traffic. While these installations are limited in number, they are, however, all made in representative organizations, which, for the most part, are among the largest and most important of their kind. The hourly traffic of five installations is graphically shown in Figs. 14A and 14B. Curves for the same installation but for different days, show an unexpected similarity. It will be seen that the traffic of installation 21, a large daily newspaper, continues pretty well through the night, in fact the busy hour is so included. On the other hand, the traffic of the remaining installations originates almost entirely between the hours of eight in the morning and six in the evening.

A total of three hundred or more observations were taken at seven of the commercial installations in order to determine the average length of conversation and the speed of operation on local connections. The average results in seconds for each installation are given below.

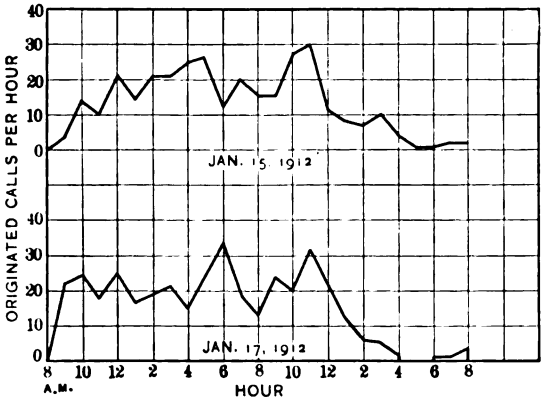


FIG. 14B.—HOURLY TRAFFIC—ORIGINATED CALLS
Installation No. 21, Newspaper Office

Installation Number	To Call	To Answer	Talking	Total
15	2.17	10.	59.6	71.77
19	2.2	7.2	62.4	71.8
21	2.2	10.4	54.2	66.8
30	1.9	11.	33.5	46.4
31	2.0	9.7	54.5	66.2
32	1.8	12.	32.1	45.9
35	2.4	7.7	41.5	51.6
—	——	——	——	——
Average	2.1	9.7	48.2	60.0

In the second column of this table is given the elapsed time between the removal of the receiver, as indicated by the plunging in of the line switch, and the selection of the line called, as indicated by the stepping of the side switch of the mechanical operator into its third or final position. The average time required to answer is given in the next column and in the next two columns, the average length of conversation and the total elapsed time, respectively. It will be seen that the average time required to establish a connection between the calling and called lines, is but 2.1 seconds. Compare this with 3.5 seconds, the average time required by an " A " operator in a well maintained manual system, to answer a call under normal operating conditions. This latter figure, furthermore, applies to central offices of the most modern type, and it will be admitted without argument that the average time of answering in manual private exchanges, in which heavy overloads are frequent, is much longer. From these remarks, it will be seen that it takes less time to establish a local connection in an automatic private exchange system, than is required by an operator to even answer a call in a manual system.

The following represents the average performance of the mechanical operators of installation No. 15, a typical traffic curve for which is shown in Fig. 14A.

Number of mechanical operators	8
Number of stations	75
Originated calls per working day	1150
Average rate of calling per station per working day	15.3
Originated calls, busy hour	180
Ratio, busy hour, to entire day	15.5 per cent
Originated calls per mechanical operator per busy hour	22.5
Originated calls per month of 26 days	29,900
Average overflow calls per month, (Average for 4 months, minimum 181, maximum 285.)	230
Ratio of overflow to originated calls	0.77 per cent
Total originated calls per year	359,000
Total calls per mechanical operator per year	45,000

Sufficient data has not yet been obtained to determine with any degree of accuracy, the capacity of the in and out automatic trunks. The number of trunks in commercial installations is more or less arbitrary, and depends upon how many the subscriber is willing to pay for. In apartment house installations, two out- and one in-trunk have been provided for 25 line installations and two out and two in for 50 line installations.

Some First Costs

The first costs of apartment house automatic switchboards placed in position, ready for operation, are shown in Fig. 15, curve *A*. These costs include all factory and shop labor and material, storage battery, all miscellaneous power wiring and the installation labor and material necessary to place the boards in

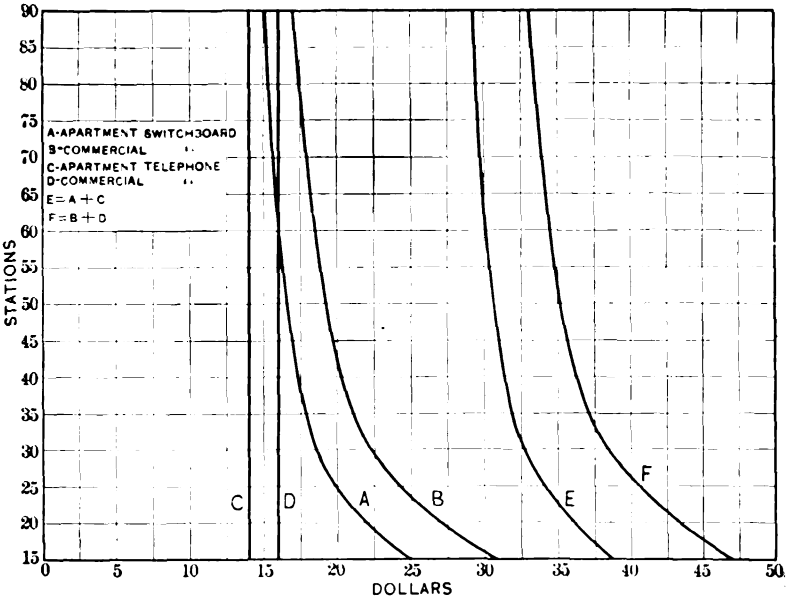


Fig. 15.—First Costs per Station—Automatic Installations

actual service. The corresponding costs of commercial automatic private exchange switchboards are shown by curve *B*. The first cost of apartment house and commercial telephones installed are shown by *C* and *D* respectively, the former includes in addition to the telephone, installation labor, but not wire. The commercial telephone costs, curve *D* include both installation labor and wire. The summation of these first costs of apartment house and commercial installations are given by *E* and *F*, respectively. The switchboard costs refer to locally made boards, in the manufacture of which high-priced day labor was used. It is, therefore, reasonable to assume that a considerable reduction in these costs could be made were the boards to be manufactured in a large factory especially adapted for the purpose.

The corresponding costs of manual private exchange installations, are shown in Fig. 16. The first costs of apartment house and commercial switchboards, curves *A* and *B* respectively, include the switchboards installed and connected, ready for immediate operation. They do not, however, include storage batteries, since the majority of such boards obtain their current supply from the nearest central office over a group of cable pairs. The first costs of apartment house and commercial telephones installed, are shown by *C* and *D* respectively and the total costs of complete installations by *E* and *F* respectively. In the preparation of these costs, the prevailing prices of the so called independent manufacturers of telephone apparatus were used.

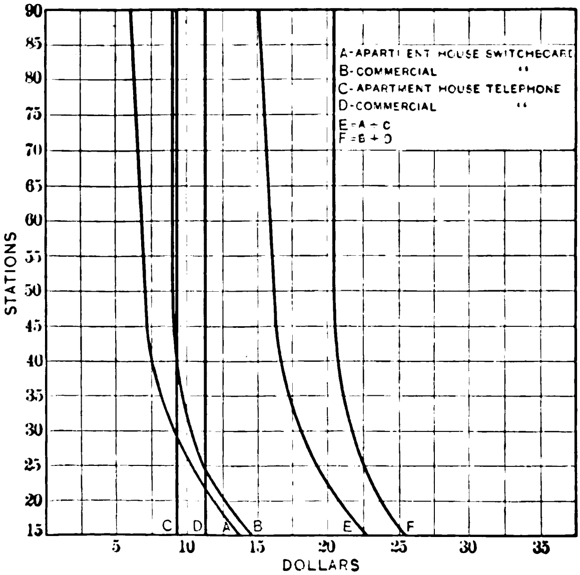


FIG. 16.—FIRST COSTS PER STATION—MANUAL INSTALLATIONS

Neither Figs. 15 or 16 include any central office costs, overhead charges, underground or aerial cable costs, nor the cost of the lateral into the building and its associated main terminal.

A comparison of the costs shows that for the largest installations, the automatic system is approximately 60 per cent more costly than the manual system and for the smallest installation 85 per cent more costly.

SOME ANNUAL COSTS

Item 1. *Maintenance Labor.* Up to the present time, data collected from 26 installations show that the average labor cost of maintaining commercial automatic private exchange installations, both switchboards and telephones, is approximately $3.00 per station per year, and of apartment house installations, $1.18 per station per year. The Bay Cities Home Telephone Company operate, in addition to the automatic private exchanges, a large number of manual private exchanges. From the data afforded by these installations, it is estimated that the average labor cost of maintaining commercial manual installations, exclusive of calling device trouble, is approximately $1.50 per station per year, and of apartment house manual installations, $0.60 per station per year. None of these figures include overhead charges and supervision, nor do they include the cost of operating and maintaining the central office plant and the underground and aerial cable systems. The difference between the charges for the commercial and apartment house installations may be attributed to the fact that the traffic, with the resulting wear and tear, is much heavier in the commercial installations.

Item 2. *Depreciation, Interest and Taxes.* The average life of manual private exchange switchboards, is considered, I believe, by the Bell companies, to be approximately 10 years, which would make the depreciation of this class of equipment 10 per cent. This comparatively short life, is due to the fact that the switchboard is exposed to extremely rough and severe usage. The items which receive exceptionally hard service, are the highly finished cabinet, plugs, cords, jacks and keys. Much of the latter equipment is soon broken and worn beyond repair. The refinishing of a cabinet for a new or re-installation is costly. The automatic switchboard, on the other hand, includes a practically indestructible metal framework, which affords complete protection to the automatic apparatus located within. This apparatus contains no parts, which when worn out, require the replacement of the whole. Those parts subject to wear are not costly and are easily replaced, and in fact are replaced as part of the regular maintenance work. Furthermore, automatic apparatus is not handled in the sense that manual apparatus is handled, which permits the wear and tear to take place in the parts designed to allow for such wear and tear. From these remarks it would seem reasonable to assume that an automatic switchboard will outlast a manual switchboard to a considerable extent and in this paper, a depreciation charge of 8 per cent will be used. The necessity for even this charge is primarily to provide for changes in the art which may require the replacement of the switchboards or parts of them, before they are actually worn out. Including average interest a 3½ per cent and taxes at 1½ per cent, it will be seen that the total of the three items in question, for automatic and manual switchboards, is 13 per cent and 15 per cent respectively.

Depreciation, interest and taxes on telephone apparatus has been taken at 17½ per cent for both automatic and manual. The figures previously given allow for an increase in the maintenance of the automatic telephone to care for the calling device.

Item 3. *Current Supply and Miscellaneous Costs.* For a year of 312 working days, it can be shown from direct meter readings, that the average cost of power consumed in commercial automatic installations at 4 cents per kw-hr. by one call per day for one year, is 2.5 cents. It may also be shown, on the basis of a year of 365 days, that the annual cost of the power consumed in an apartment house automatic installation at 4 cents per kw-hr. by one call per day, is approximately 5 cents. The difference between these two figures may be attributed to the fact that in the latter system considerable power is wasted in maintaining the batteries in their proper condition. In addition to the cost of power consumed, each installation must be charged with the annual cost of four cable pairs, one for charging, one for the busy tone and ringing interrupter, one for ringing power, and one for supervision. The average length of cable circuit is estimated at one half mile, which at the present time conforms very closely to the actual conditions prevailing in San Francisco. The total annual cost of No. 22 B. & S. gage cable including all charges is taken at $3.00 per pair per mile which makes the total annual cost of the four pairs $6.00.

Power for manual private exchange switchboards, within a radius of one half mile is almost invariably supplied from the nearest central office storage battery over a group of cable pairs. Within this limit, such an arrangement is nearly always the most economical. The average power consumed per connection, by the manually operated private exchange switchboards of the Bay Cities Home Telephone Company is 0.1 watt-hr. and with power at the storage battery bus bars at 5 cents per kw-hr. amounts to approximately 0.156 cents per year, for one call per day—a negligible amount. Since the size and cost of feeders depend upon the average maximum instantaneous current requirements, it is essential that the ratio of the busy hour to the entire day be known. Here the ratio of 15.5 per cent derived from the data afforded by installation 15, will be taken. This is somewhat lower than the ratio met with in most private exchanges, and therefore, favors the feeder method. Upon this assumption it can be shown that the annual cost of a feeder, one half mile in length and serving a manual private exchange switchboard of the type used by the Bay Cities Home Telephone Company, is approximately 1.63 cents per call per day.

In addition to these two costs, each manual installation must be charged with $1.50 as the annual cost of the cable pair supplying ringing generator current.

Item 4. *Operating Costs.*

Automatic Apartment House Systems. No operator required.

Commercial Automatic Systems. In, out and local calls are assumed equal. This at once eliminates the operator from two-thirds of the total calls. It is estimated that 80 per cent of the remaining in-calls will be made direct, which leaves but 6.7 per cent of the total calls to be handled by an operator. The few calls of this nature, in most installations, may well be handled by a clerk who has other duties to occupy his or her full time. Upon the assumption that the average salary paid such a party is $45.00 a month and that with full time devoted to operating, 500 calls a day can be handled, it will be seen that the cost of handling each call is 0.35 cents.

Apartment House Manual Systems. The rate of calling is not a controlling factor in determining the cost of operator hire in apartment houses served by manual switchboards. The quality and extent of service is largely dependent upon the management. The more pretentious apartment houses, generally give the more extensive and therefore, more costly service. The following schedule is based upon observations made in and around San Francisco.

30 apartments or less, one day operator at $35.00 per month. Evening service given by proprietor, janitor or elevator boy, as the case may be.

31 to 50 apartments, one day operator at $35.00 and one night operator to 10 p.m. at $20.00, a total of $55.00 a month.

Above 50 apartments, one day operator at $35.00 and one night operator to 12 p.m. at $35.00, a total of $70.00 a month.

Commercial Manual Installations. Data collected in San Francisco, show that the full time of an operator is required for private exchange work when the number of all classes of connections handled per day is between 500 and 1000. With less than 500 calls an operator may devote her spare time to other duties.

It is estimated that $45.00 is a fair salary for a first class commercial private exchange operator. This sum, however, is less than the average received by operators in San Francisco, concerning which information has been obtained.

COMPARISON OF ANNUAL COSTS

Corresponding annual costs of automatic and manual private exchanges are given in Fig. 17. Those costs pertaining to commercial installations apply in particular to exchanges equipped to handle a total of approximately 20 in, out and local calls per station per day. Two in and two out calls per station per day are provided for in the costs of the apartment house installations.

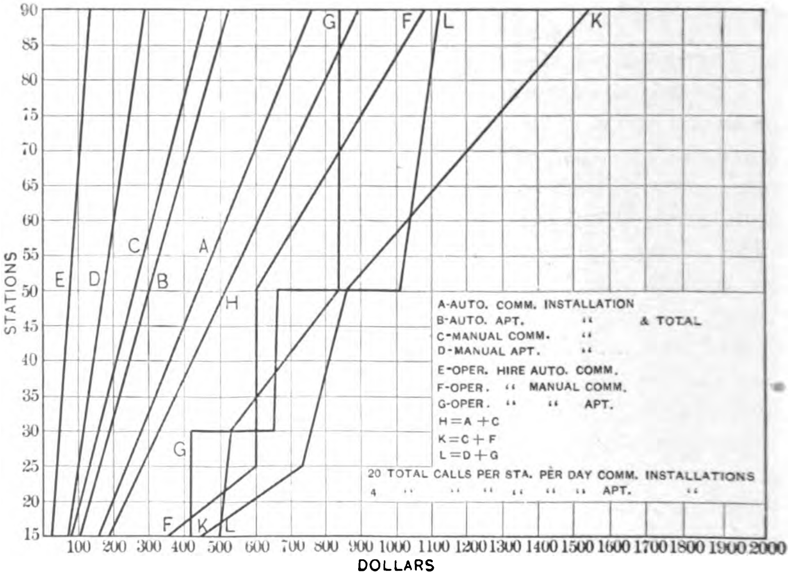


FIG. 17.—COMPARATIVE ANNUAL COSTS

Curves *A* and *B* represent the summation of all costs included in items 1, 2 and 3, for commercial and apartment house automatic installations respectively. Curves *C* and *D* represent the corresponding costs of manual installations. The costs of operator hire, item 4, in commercial automatic installations, are given by *E*, and in commercial and apartment house manual installations by curves *F* and *G* respectively. Curve *H* gives the total annual costs of commercial automatic installations including operator hire. Curves *K* and *L* give respectively, the corresponding costs of commercial and apartment house manual installations.

The most striking feature in the results set forth in Fig. 17, that the cost of private exchange operator hire alone, in manual installations, is greater than the total annual cost of operating and maintaining automatic installations. Considering the total costs of each it will be seen that the annual costs of the manual system are from 70 per cent to 300 per cent greater than the annual costs of the automatic system. Eliminating operator hire, the annual costs of the automatic system is from 60 per cent to 90 per cent greater than the manual system.

RECAPITULATION

In the foregoing pages, an attempt has been made to show that the automatic private branch exchange is practicable and economically possible. The pertinent questions still unanswered are these. Do the advantages claimed for it, justify its general installation in commercial organizations and apartment houses in preference to the manually operated private exchange, and is automatic equipment reliable? The answer to the first question will be found in a further discussion of some of the distinguishing features of the atuomatic private exchange.

The elimination of or reduction in operator hire, made possible by the installation of automatic equipment, results as has been shown, in a saving, more than sufficient to pay for the entire cost of maintaining an automatic exchange. The complete elimination of the operator from apartment house installations might be objectionable were it not possible to make use of the information bureau, a department maintained by every telephone company. The results obtained in San Francisco show that the increase in cost of operation necessary to properly handle information calls for the occupants of apartments, is negligible. Where the period of occupancy is more than a few months, " extra listing " in the directory affords the tenant the equivalent of main line service in every respect. The substantial elimination of the private exchange operator by the installation of automatic private exchanges affords the telephone company an additional source of revenue—an opportunity which should not be overlooked—for it has been shown that the maintenance and first costs of automatic exchanges are materially higher than manual exchanges, thus permitting higher rates with a saving to the subscriber and a greater return to the telephone company for a given number of stations.

Anyone who uses or has used an automatic private exchange for local intercommunication must realize the advantage this system has in this respect, over the old. Local calling differs somewhat from exchange calling in that the numbers of the locals to which the majority of calls are made can be easily memorized, or at the most, placed on a slip of paper easily reached, thus making the effort required in calling, little more than that required to depress a push button to call the office boy. With reference to exchange calling, it is sometimes argued that patrons of manual private exchanges prefer to have the private exchange operators obtain numbers for them, rather than ask for a trunk to the central office and obtain the number for themselves, and that the automatic private exchange is wanting in this respect. This practice of indirect calling in manuals ystems is now quite generally followed throughout the country, even though the telephone companies discourage it as much as possible. The argument in favor of this practice, from calling subscriber's viewpoint, is that he would otherwise have to repeat his instructions to at least two operators, and in case the call were for another private exchange subscriber, to three operators, with a possibility always of from one to three delays. The calling subscriber, therefore, can hardly be blamed for placing the burden of such calls upon the private exchange operator, when one is available. The subscriber who receives such a call, however, has a somewhat different viewpoint even though he may be guilty of the practice himself, when calling, for he is asked his name by the operator and then politely told to hold the line while she calls the first subscriber back on the line. It quite often happens, particularly if there is a delay in getting a party, that the calling subscriber engages in other work and does not answer the call promptly. This naturally tends to irritate the subscriber who has been called. From any viewpoint it must be admitted that even if direct calling is burdensome, it is an imposition to place the burden upon the called subscriber. In comparison with this tedious and indirect method made necessary by the introduction of manually operated private exchanges into manual exchange areas, it is well to note that the introduction of automatic private exchanges into automatic exchange areas does not require a change in operating methods, the subscriber is merely required to call from one to three additional digits each requiring on an average, an addition of one second to the calling time. Other than this the subscriber handles the call in every detail, as though it were being made from one main line to another. Patrons to main line manual service, and to the well known multi-key intercommunicating privateexchange service, do not object to getting numbers themselves. It is, therefore, reasonable to assume that patrons to manual private exchange service would likewise not object, providing the introduction of the manual private exchange did not introduce additonal delays and more cumbersome operating methods. To illustrate more clearly the simplicity of calling in the automatic system and the multiplicity of indirect calling in the manual system, in both cases from and to a private exchange I beg to call attention to the following tabulation in which the time required by the different stages of the calls are given. The figures with reference to speed of operation in the manual system represent the average of good service in a large, well maintained multi-office exchange. It has been assumed that private exchange and central office operators are equally efficient, a condition not realized in actual practice. I believe that not even the most ardent advocate of the manual system will disagree with me when I say that at least 15 per cent of the total originated calls in any well run manual exchange require from 4 to 12 seconds or more to answer. If this is so, a correspondingly greater number of delays must be expected when three operators are involved. All delays of this nature are eliminated by the automatic system.

	Automatic System	Manual System
Calling number, 8 digits	8 sec.	
Answering first P. B. X. operator		3.5 sec.
Giving instructions and making connections		8.5 "
Answering " A " operator		8.5 "
Making connections in central office (80 per cent trunking)		13. "
Answering second P. B. X. operator		3.5 "
Giving instructions and making connections		8.5 "
Answering subscriber (from preceding traffic data)	9.7 sec.	9.7 "
Ringing and answering of calling subscriber		3.5 "
Conversation (from preceding traffic data)	48.2 "	48.2 "
Disconnection P. B. X. operator		3.5 "
Disconnection " A " operator		3.5 "
Total elapsed time	65.9 sec.	108.9 sec.

Upon the assumptions given it will be seen that the total time involved in a connection through the manual system is 65 per cent greater than in a connection through the automatic system It will also be seen that in the latter system the subscriber is required to wait but 17.7 seconds for an answer as against at least 50.2 seconds in the manual system. Furthermore, in the automatic system, the busy tone, in case the line called is busy is obtained in eight seconds, whereas 45 seconds must elapse before a similar report can be obtained through a manual system.

Even though the indirect method of calling is not deemed necessary in an automatic system, it can, however, be provided for where conditions require, as is illustrated by the special arrangements made in one installation, whereby the clerks of certain officials establish the outgoing exchange connections and answer the incoming exchange connections. The local calls only, are originated and answered by the officials. The desired result is obtained by placing two ringers on each line, one at the clerk's desk, adapted to ring on incoming exchange calls only, and the other on the official's desk adapted to ring on local calls only. Secrecy is afforded by causing the clerk's telephone to be automatically cut off when the official is using the line. The circuit is further adapted to permit the official and clerk to converse with each other without being overheard by a calling party.

Secrecy on all connections, instantaneous disconnection upon hanging up and the fact that the full value of the service is available 24 hours each day and every day in the year, are all arguments for the automatic private exchange.

Proponents of the manual system have always put forth the argument that subscribers, as a whole, object to the fundamental principle of the automatic system, which requires them to call numbers with a dial or other calling device. Actual investigations, so far as I have been able to ascertain, have never substantiated this statement. In fact, I believe such investigations as have been made in cities where an automatic system is in proper operation, show that the public as a whole, prefer this system to the manual. It will be admitted that there are many people whose time is so valuable that it may not be wasted. Such people, however, are nearly always provided with an ample force of clerks upon which the burden of calling may be placed, whether it be in a manual or an automatic system.

Calls for toll or long distance service from an automatic or in fact any private exchange, must be checked by some responsible party, if abuse of this service is to be prevented. In San Francisco an automatic private exchange subscriber calls the toll opperator in the usual way, which operator in establishing the connection refers the call back to the receiving cabinet operator, who takes note of it and extends the connection to the originating station. Correspondingly simple methods have also been worked out to handle " two-number " business without delay.

It was not without some apprehension that the first automatic private exchange installation was made. Many doubts were expressed as to its reliability and its ability in general to give service without undue cause for complaint. It was known, as stated in the first part of this paper, that the unattended sub-office was a success, but the extreme smallness of the unit, the inability to control the surrounding conditions with regard to temperature, dust and moisture, and the non-uniform potential of the current supply, were all unknown factors, each capable of seriously affecting the operation of the switchboard. The success, however, of the first installation immediately caused this feeling of doubt to give way to one of confidence, which feeling was further augmented by the fact that the apparatus used was primarily not intended for the purpose to which it was put. The untold possibilities for improvement in the design and manufacture of automatic apparatus, so as to decrease the cost of maintenance, is, I believe at least one feature that assures the future of the automatic private exchange.

The final test of any public utility is its ability to satisfy the public and from this viewpoint the automatic private exchange has not been found wanting. A complete record of all complaints received from all sources is kept by the Bay Cities Home Telephone Company. During the operation of installation 15, which covers a period of eight months, 173 complaints were received resulting in 221 recorded cases of trouble and comments, which, together with the record of installation 21 for four months, are given here in detail.

Complaints from installation 15 average one for each 1400 originated calls and from installation 21, one for each 1480 originated calls. During the entire year of 1911, 29 complaints were received from apartment house installation 1, an average of one for each 450 outgoing calls. These complaints might easily be a serious matter were their nature such as to interfere with the service of the installations as a whole. An examination of all records does not reveal a single case where an entire switchboard was put out of service. On the contrary, substantially all trouble affected but one line or one trunk. The foregoing records of installations 15 and 21 show that the actual private exchange switchboard trouble was but 4 per cent greater than the trouble due to broken and bent station apparatus, caused by rough handling on the part of the subscribers. One station of installation 15 shows a record of three new receiver shells in one month. Of the 173 complaints received, from installation 15, all were recorded O.K. within 11½ hours. 94 per cent within 6 hours, 80 per cent within 3½ hours, 70 per cent within 2 hours, 45 per cent within 1 hour and 11 per cent within 15 minutes, which 11 per cent includes all of the more serious troubles such as a sticking switch or a blown fuse.

Character of Trouble	Installation No. 15			Installation No. 21		
	No. of Cases	Per cent of total		No. of Cases	Per cent of total	
C. O. Switchboard	2	.9		none		
P. B. X.	43	19.4		15	24.2	
Calling device	50	22.6		6	9.7	
Broken & bent station apparatus	35	15.85	51.3	13	21.0	45.2
Other station apparatus trouble	35	15.85		9	14.5	
Inside wiring	1	.45		1	1.6	
U. G. Cable	none			none		
Misuse	3	1.35		none		
Slow to answer	5	2.3		2	3.2	
Don't answer	5	2.3		1	1.6	
O. K. on test	42	19.0		15	24.2	
Total	221	100		62	100	

A manual private exchange switchboard is built primarily to accommodate an operator. The automatic private exchange switchboard, on the other hand, is built to facilitate the up-keep of the apparatus located within it and may be opened for inspection at any time, without inconveniencing anyone. A manual switchboard can rarely be gotten at during working hours, without seriously inconveniencing the operator, which makes the remedying of the fault more difficult and costly.

The automatic private exchange, may with slight modifications be readily adapted to manual exchange areas. In such areas it would afford direct intercommunication and direct out-going exchange service. Obviously, all incoming calls would have to be made through the receiving cabinet, unless the central office operators were provided with a means of calling, concerning which a word will be said later. It will be seen at once that a reduction of at least 66 per cent in operator hire can be made in commercial private exchange installations by using automatic equipment. A further reduction should be possible since the automatic system does not require supervision on the part of the attendant after a connection has once been established. In apartment houses, the services of a telephone operator, could in many cases, be dispensed with by placing the small receiving cabinet in the elevator where it may be looked after by the elevator boy. At first thought it might appear that a cabinet so located would seriously affect the quality of service. With proper design and supervision, however, this need not be the case, since the elevator boy would be required to do nothing more than to extend the call to the proper apartment. Should the line called be busy the busy tone will be automatically given to the calling subscriber, and should the party fail to answer, the continuous recurrence of the ringing interruptions now well understood by the public, although they have never been mentioned in any instructions, would indicate that the party called does not answer.

An automatic private exchange switchboard can easily be adapted to serve any number of exchanges within its capacity, for example a 90 line board could be installed in an office building and adapted to serve nine 10 line installations or it could be installed in some one apartment house and adapted to serve six 15 line installations. With a switchboard so arranged, it would also be possible, where a number of small apartment houses or flats are erected within the same block, to place a receiving cabinet in some one apartment house and allow it to serve all houses, the proprietors of the different houses sharing the expense.

In many cities a general demand has been made of late by apartment house proprietors and owners for a service which does not require apartment house operators or attendants. This demand has been met in manual exchanges to some extent, by installing in each apartment, main or party lines equipped with coin machines. Such service is obviously costly where any great amount of cable is involved and has the objection that many people do not want coin machines or party lines, and furthermore, requires much space on the main switchboard for which the return is not always adequate. All these objections, can, I believe, be overcome by the installation of automatic private exchanges for by so doing the telephone company could place in the central offices, operators provided with special equipment adapted to operate such switchboards, and by the proper adjustment of rates could place, and rightly so, the burden of the additional operators upon the houses they serve. The cost of service under such an arrangement, particularly to the small apartment houses, would be very much less than it is now with a separate operator in each establishment, and, by confining the operators to the central offices, 24 hour service would be possible, a point not to be overlooked as an argument for higher rates. While it may be economical to substitute central office operators in this manner in a manual exchange for apartment house operators, such a course would not necessarily be the proper one when applied to commercial private exchange installations, for in nearly all such installations, the operator, as before stated, may be assigned other duties, and in this way, his or her full time used to the best advantage, a condition not possible in apartment houses, where other work cannot be found for an operator.

While the automatic private exchange may be considered a success in the larger cities and towns, the development of automatic apparatus in general, has not yet reached the stage where it may be placed in localities which cannot afford ample skilled labor to look after it. Automatic equipment, like a watch, need not require much attention but when attention is required, quality and not quantity should be considered. It should not be inferred from this that skilled labor is hard to get in the larger cities, for if San Francisco may be taken as an indication of what may be expected elsewhere, it is not. The work is interesting and ambitious men take to it readily. There are, no doubt, many other conditions under which the automatic private exchange is not yet fitted to give the best service, but the installations referred to in this paper, demonstrate, I believe, beyond a reasonable doubt, the ability of the automatic private exchange to satisfactorily serve the average commercial organization and apartment house in a more economical manner than is now possible with the manually operated private exchange.

CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Adopted by the Board of Directors, March 8, 1912.

A. General Principles.
B. The Engineer's Relations to Client or Employer.
C. Ownership of Engineering Records and Data.
D. The Engineer's Relations to the Public.
E. The Engineer's Relations to the Engineering Fraternity.
F. Amendments.

While the following principles express, generally, the engineer's relations to client, employer, the public, and the engineering fraternity, it is not presumed that they define all of the engineer's duties and obligations.

A. General Principles

1. In all of his relations the engineer should be guided by the highest principles of honor.

2. It is the duty of the engineer to satisfy himself to the best of his ability that the enterprises with which he becomes identified are of legitimate character. If after becoming associated with an enterprise he finds it to be of questionable character, he should sever his connection with it as soon as practicable.

B. The Engineer's Relations To Client Or Employer

3. The engineer should consider the protection of a client's or employer's interests his first professional obligation, and therefore should avoid every act contrary to this duty. If any other considerations, such as professional obligations or restrictions, interfere with his meeting the legitimate expectation of a client or employer, the engineer should inform him of the situation.

4. An engineer can not honorably accept compensation, financial or otherwise, from more than one interested party, without the consent of all parties. The engineer, whether consulting, designing installing or operating, must not accept commissions, directly or indirectly, from parties dealing with his client or employer.

5. An engineer called upon to decide on the use of inventions, apparatus, or anything in which he has a financial interest, should make his status in the matter clearly understood before engagement.

6. An engineer in independent practice may be employed by more than one party, when the interests of the several parties do not conflict; and it should be understood that he is not expected to devote his entire time to the work of one, but is free to carry out other engagements. A consulting

engineer permanently retained by a party, should notify others of this affiliation before entering into relations with them, if, in his opinion, the interests might conflict.

7. An engineer should consider it his duty to make every effort to remedy dangerous defects in apparatus or structures or dangerous conditions of operation, and should bring these to the attention of his client or employer.

C. OWNERSHIP OF ENGINEERING RECORDS AND DATA

8. It is desirable that an engineer undertaking for others work in connection with which he may make improvements, inventions, plans, designs, or other records, should enter into an agreement regarding their ownership.

9. If an engineer uses information which is not common knowledge or public property, but which he obtains from a client or employer; the results in the form of plans, designs, or other records, should not be regarded as his property, but the property of his client or employer.

10. If an engineer uses only his own knowledge, or information which by prior publication, or otherwise, is public property and obtains no engineering data from a client or employer, except performance specifications or routine information; then in the absence of an agreement to the contrary the results in the form of inventions, plans, designs, or other records, should be regarded as the property of the engineer, and the client or employer should be entitled to their use only in the case for which the engineer was retained.

11. All work and results accomplished by the engineer in the form of inventions, plans, designs, or other records, that are outside of the field of engineering for which a client or employer has retained him, should be regarded as the engineer's property unless there is an agreement to the contrary.

12. When an engineer or manufacturer builds apparatus from designs supplied to him by a customer, the designs remain the property of the customer and should not be duplicated by the engineer or manufacturer for others without express permission. When the engineer or manufacturer and a customer jointly work out designs and plans or develop inventions a clear understanding should be reached before the beginning of the work regarding the respective rights of ownership in any inventions, designs, or matters of similar character, that may result.

13. Any engineering data or information which an engineer obtains from his client or employer, or which he creates as a result of such information, must be considered confidential by the engineer; and while he is justified in using such data or information in his own practise as forming part of his professional experience, its publication without express permission is improper.

14. Designs, data, records and notes made by an employee and referring exclusively to his employer's work, should be regarded as his employers property.

15. A customer, in buying apparatus, does not acquire any right in its design but only the use of the apparatus purchased. A client does not

acquire any right to the plans made by a consulting engineer except for the specific case for which they were made.

D. THE ENGINEER'S RELATIONS TO THE PUBLIC

16. The engineer should endeavor to assist the public to a fair and correct general understanding of engineering matters, to extend the general knowledge of engineering, and to discourage the appearance of untrue, unfair or exaggerated statements on engineering subjects in the press or elsewhere, especially if these statements may lead to, or are made for the purpose of, inducing the public to participate in unworthy enterprises.

17. Technical discussions and criticisms of engineering subjects should not be conducted in the public press, but before engineering societies, or in the technical press.

18. It is desirable that first publication concerning inventions or other engineering advances should not be made through the public press, but before engineering societies or through technical publications.

19. It is unprofessional to give an opinion on a subject without being fully informed as to all the facts relating thereto and as to the purposes for which the information is asked. The opinion should contain a full statement of the conditions under which it applies.

E. THE ENGINEER'S RELATIONS TO THE ENGINEERING FRATERNITY

20. The engineer should take an interest in and assist his fellow engineers by exchange of general information and experience, by instruction and similar aid, through the engineering societies or by other means. He should endeavor to protect all reputable engineers from misrepresentation.

21. The engineer should take care that credit for engineering work is attributed to those who, so far as his knowledge of the matter goes, are the real authors of such work.

22. An engineer in responsible charge of work should not permit non-technical persons to overrule his engineering judgments on purely engineering grounds.

F. AMENDMENTS

Additions to, or modifications in, this Code may be made by the Board of Directors under the procedure applying to a by-law.

HISTORY OF THE CODE

At the Milwaukee Convention in May, 1906, Dr. Schuyler Skaats Wheeler delivered his presidential address on "Engineering Honor." It was the sense of the Convention that the ideas contained in this address should be embodied in a Code of Ethics for the electrical engineering profession, and to this end the following committee was appointed in October, 1906:

SCHUYLER SKAATS WHEELER, *Chairman.*
H. W. BUCK CHARLES P. STEINMETZ

In May, 1907, the committee reported a code to the President and Board of Directors for discussion at the June Convention at Niagara Falls. It was discussed and adopted by the Convention but later the adoption had to be set aside on account of the provisions of the Constitution prohibiting

Conventions from acting upon questions affecting the Institute's organization or policy.'

It was taken up by the Board of Directors on August 30, 1907, revised, printed and submitted to the membership for suggestions to be sent to a new committee appointed by President Stott.

It lay dormant until June, 1911, when, in accordance with a resolution of the Board of Directors, President Jackson appointed a committee. The personnel of this committee, as reappointed by President Dunn in August, 1911, is as follows:

GEORGE F. SEVER, *Chairman*.

H. W. BUCK	CHARLES P. STEINMETZ
SAMUEL REBER	HENRY G. STOTT

SCHUYLER SKAATS WHEELER

This committee's work was presented in a report to the Board of Directors on February 9, 1912, when the code was tentatively adopted. After a month's careful analysis and consideration of numerous suggestions from the advisory members of the committee and others, the completed code was adopted at the meeting of the Board of Directors on March 8, 1912.

At the meeting of February 9, the title of the committee and of the code was changed from that of Code of Ethics to Code of Principles of Professional Conduct.

The committee was assisted by eighteen advisory members appointed by the President. Their names are appended.

WILLIAM S. BARSTOW
LOUIS BELL
JOHN J. CARTY
FRANCIS B. CROCKER
DUGALD C. JACKSON
A. E. KENNELLY
JOHN W. LIEB, JR.
C. O. MAILLOUX
RALPH D. MERSHON
HENRY H. NORRIS
RALPH W. POPE
HARRIS J. RYAN
CHARLES F. SCOTT
SAMUEL SHELDON
WILLIAM STANLEY
LEWIS B. STILLWELL
ELIHU THOMSON
W. D. WEAVER

PROCEEDINGS

of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

SECTION II

Papers, Discussions and Reports

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THE APPLICATION OF AUTOMATIC SELECTING DEVICES TO TELEPHONE MULTIPLE SWITCHBOARDS

BY ALFRED H. DYSON

This paper will discuss means and certain results obtained by the application of selective switches to common battery multiple telephone switchboard systems.

The manual common battery multiple telephone switchboard system has now been in commercial use in practically all of the larger cities for more than a decade. As at present used its arrangement has reached the limit of development and is structurally the least complex of all telephone systems adapted to provide service for a large number of subscribers, but when applied to the larger sized exchanges it is found to be very expensive in first cost and also is believed to be unnecessarily expensive in operation. Its first cost increases in an increased ratio with the increased number of lines. This is also true of its operation, for the reason that with the increase in number of subscribers' lines the number of calls per line per day also increases, with the result that the ratio between the number of lines and the number of operators for effecting the connection of such lines is decreased, that is, the percentage of operators to lines is increased.

Briefly, the arrangement of the manual multiple switchboard system, as now in use, is such that each subscriber's line terminates on the switchboard in an answering jack with which is associated a signal lamp and multiple jacks, there being as many multiple jack terminals of each line as there are sections of switchboard,—each section consisting of three operators' positions. For the interconnection of a line as a calling line with a line as a called line there are provided what are termed connecting cord circuits, each provided with a pair of plug terminals known as answering and calling plugs, and a pair of signal lamps termed answering and calling supervisory lamps. Each cord circuit is in addition provided with keys which enable the operators to connect in circuit their telephone apparatus and to establish circuit for the ringing current for actuating the signal bells of the substations. There are placed before each operator answering jack terminals of as many lines as an operator is capable of establishing connections for and as many connecting cord circuits—usually about fifteen—as are required to establish such connections at the busiest moment.

If it be a multi-office exchange, there are provided multiple jack terminals of trunk lines which lead from each office to each of the other offices of the exchange, there being a multiple jack terminal of each trunk within the reach of each subscriber's operator. In addition there are provided in each office as many incoming trunk circuits as may be required to handle the connections trunked into a particular office from the other offices. These circuits are each provided with two signal lamps termed calling supervisory and disconnect lamps, and keys for establishing circuit for current for actuating the signal bells of the called substations. These incoming trunk circuits usually terminate in connecting plugs before special operators, usually called incoming trunk or B operators, as distinguished from the subscribers' operators, who are sometimes called A operators. There are as many incoming trunk circuits placed before each such operator as may be handled by an operator during the busiest moment, *i.e.*, during the moment of the greatest number of coexisting trunk connections. Usually an operator is provided with about 30 such circuits. There is also provided before the incoming trunk operators a multiple jack terminal for each line of the office, there being one such terminal for every three or less operators.

The operation of the multiple switchboard system is such that upon the removal of the receiver from the switchhook by a calling subscriber the line signal lamp of the line of such subscriber is automatically illuminated. The operator before whom said lamp is located, upon observing that it is lighted, inserts the answering plug of an idle cord circuit into connection with the answering jack of the line of the subscriber, and by the actuation of a key associated with the cord circuit it is connected telephonically with the calling subscriber. The operator thus ascertains the number of the called subscriber. If it be a single office exchange, the operator by touching the sleeve terminal of the multiple jack of the line of the wanted subscriber with the tip of the associated calling plug of the cord circuit ascertains the busy or idle condition of the line. If the line be busy the calling subscriber is notified that connection cannot be established. If the line be idle she then inserts said calling plug into connection with the said multiple jack terminal and actuates a key associated with the cord circuit, which results in the transmission of current over the called line to actuate the substation signal bells. The projection of the ringing current thereafter continues periodically until the removal of the receiver from the switchhook of the called substation, at which time the ringing current is permanently disconnected from the line and the calling and called subscribers automatically placed in telephonic connection. Whenever the plugs of a cord circuit are in connection with a line and the receivers off the switchhooks the supervisory lamps are in their normal or unlighted. condition, but upon replacing the receiver upon the switchhook at the calling substation the answering supervisory lamp is illuminated, and upon replacing the receiver upon the switchhook at the called substation the calling supervisory lamp is illuminated. The principal object of these lamps is to inform the operator when disconnection is desired, *i.e.*, when the plugs of a cord circuit should be disconnected from the jack terminals of the lines. This is done when the two connected subscribers replace their receivers upon their switchhooks after completion of conversation. These lamps are also used for the purpose of signalling the operator after a connection has been established if her assistance is desired.

If it be a " multi " office exchange and a calling subscriber desires connection with a subscriber whose line terminates in some office other than the office in which the line of the calling subscriber terminates, then the operator would communicate—by means of a call circuit—with an incoming trunk operator, in the office in which the called line terminates, giving to the incoming trunk operator the number of the line of the called subscriber. The incoming trunk operator, upon ascertaining the number of the called subscriber, assigns a trunk to be used. Upon assignment of such trunk the subscriber's operator inserts the calling plug associated, with the answering plug inserted in the answering jack, into connection with a multiple jack terminal of the trunk assigned. The incoming trunk operator, upon ascertaining the number of the called subscriber, by touching the sleeve of the multiple jack terminal of the line of the called subscriber with the tip of the plug of the trunk circuit assigned ascertains the busy or idle condition of the called line. If such line be busy the calling subscriber is notified by means of a suitable signal. If the called line be not busy the incoming trunk operator inserts the plug of the assigned trunk into connection with the multiple jack terminal of the called subscriber, and actuates a key associated with the assigned trunk, which results in the projection of current over the line to actuate the signal bells of the called substation. This ringing current continues periodically until the removal of the receiver at the called substation, or until the removal of the trunk plug from connection with the multiple jack of the line called. Upon removal of the receiver from the switchhook at the called substation the ringing current is permanently disconnected from the line and the two subscribers automatically placed in telephonic connection. The signal lamps associated with each incoming trunk circuit indicate to the incoming trunk operator when disconnection should be effected, which is accomplished by simply removing the trunk plug from connection with the multiple jack terminal of the line.

The introduction commercially of the automatic telephone system has resulted in the production of a modified form of multiple switchboard system. This system I shall herein term the "automatic call distributing system." This system materially reduces the cost of operation and also in the larger central offices reduces the first cost of the central office equipment.

The arrangement of the automatic call distributing system differs from that of the manual system in that the answering jacks, their associated line lamps and the answering cords of the cord circuits are eliminated. In lieu thereof automatic selector switches are provided which, upon the removal of the receiver from the switchhook at a calling substation, *automatically connect a calling line with the first idle connecting cord circuit* to which the calling line has access. In other words the calls are automatically distributed before the operators. There are a number of arrangements of switches for accomplishing this result.

By one arrangement a small ten point switch is provided for each line and a sufficient number of 100 point switches to accommodate the maximum number of coexisting connections. This arrangement acts in such a way that upon the removal of the receiver from the switchhook at a calling substation the ten point switch associated with the line is automatically rotated to select an idle one of ten 100-point switches which, upon selection, is automatically actuated to select and connect with an idle one of 100 connecting cord circuits. Upon the completion of the second selection a signal lamp associated with the selected cord circuit is automatically illuminated, indicating to the operator, before whom such selected cord circuit is located, that a connection is desired.

Another arrangement is to provide a 100-point switch for each connecting cord circuit and a number of 100-point line selector switches equal to the number of the maximum coexisting connections at the busiest moment of the day. The operation of this arrangement is such that upon the removal of the receiver from the switchhook, a switch associated with an idle cord is automatically actuated and selects an idle line selector, which said line selector is adapted upon its selection to automatically select a multiple terminal of the calling line. When this selection has been made a lamp signal associated with the selected cord circuit is displayed before the operator, indicating that a connection is desired.

Another arrangement, and the one preferred by the writer, is to divide the lines as calling lines into groups of 100 lines each and to provide for each group of 100 lines as many 100-point line selector switches as there will be coexisting calls in the associated group of 100 lines during the busiest moment of the day. To each line selector switch is electrically connected a 100 point cord selector switch. The operation under this arrangement is such that upon the removal of the receiver from the switchhook, by a calling subscriber, an idle one of the line selectors and its associated cord selector are actuated. The line selector automatically selects and connects with a multiple terminal of the calling line, and the cord selector automatically selects and connects with a multiple terminal of an idle cord circuit. Upon such selection of the line and cord, a signal lamp associated with the selected cord is illuminated, indicating to the operator before whom the cord and lamp are located that a connection is desired. The operator observing the lighted condition of the lamp, after actuation of a key associated with the said cord circuit, ascertains the number of the wanted substation. Thereafter—if it be a single office exchange—the operator, by touching the sleeve of a multiple jack terminal of the line of the wanted subscriber with the tip of the connecting plug of the selected cord circuit, ascertains the busy or idle condition of such line. If the line be busy she notifies the calling subscriber that connection cannot be completed. If the line be idle she inserts the connecting plug into connection with the multiple jack and actuates a key associated with the cord circuit, which projects over the called line current which actuates the signal bells of the substation of the called subscriber. This signalling current is maintained periodically until the removal of the receiver from the switchhook at the called substation. Upon such removal the signalling current is automatically disconnected and the two subscribers placed in telephonic connection. Associated with the connecting end of each cord circuit is a signal lamp termed supervisory lamp, which indicates to the operator when the called subscriber removes the receiver from the switchhook and also when the receiver is replaced. The call signal lamp associated with the answering end of the cord circuit acts also as a supervisory lamp which indicates, after connection with the called line, when the receiver at the calling substation is off or on the hook. After completing conversation the two subscribers, by replacing the receivers upon their respective switchhooks, cause the illumination of the two supervisory signal lamps, which indicates to the operator that disconnection is desired, which she accomplishes by removing the connecting plug from connection with the multiple jack terminal of the line of the called substation.

If it be a multi-office exchange and if a calling subscriber desires connection with a line terminating in some other office, then the connection is trunked to the distant office and established as described in connection with the manual system.

In order to arrive at the difference in the number of operators required and the difference in first cost between the two systems, it is necessary to know,

1. The number of calls per line per day.
2. The number of calls originating during the busiest hour.
3. The number of connections an operator can establish in a single office exchange during the busiest hour.
4. The number of connections an operator can establish in a multi-office exchange during the busiest hour.

Upon the number of calls per line per day and the number of calls an operator can establish during the busiest hour, will depend the number of lines which may be assigned as calling lines to each operator. On the number of lines assigned to each operator will depend the number of operators' positions required to handle the traffic during the busiest hour. It is also necessary to provide connecting apparatus to accommodate the maximum number of coexisting calls at the busiest moment.

For the purpose of this discussion I shall only consider flat rate service, including individual lines and a fair development of selective party lines.

In order to determine the number of calls per line per day in exchanges of various sizes and the number of connections an operator can establish in both a single office exchange and a "multi" office exchange during the busiest hour, I have had reference to "peg counts" of various exchanges approximating the sizes to be discussed.

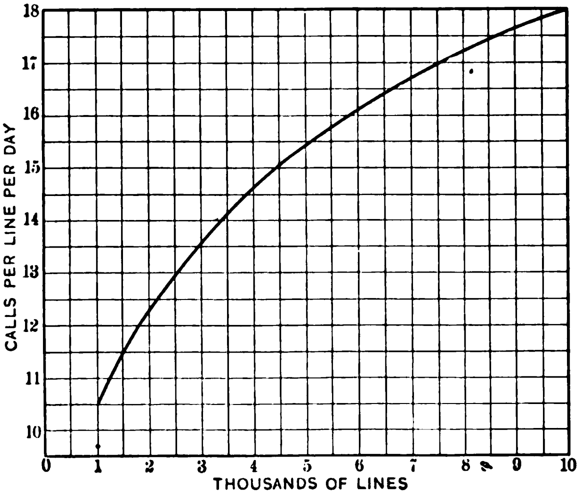

FIG. 1

Calls per line per day in exchanges varying from 1,000 to 10,000 lines. Flat rate service.

The curve of Fig. 1 illustrates the average number of calls per line per day in exchanges varying from 1,000 to 10,000 flat rate lines. I do not claim this curve to be exact for any particular exchange, as local conditions are usually such as to cause a divulgence, but it is a fair approximate average.

Curve *A* of Fig. 2 illustrates the average number of connections which operators in single office exchanges varying from 1,000 to 10,000 lines can establish during the busiest hour. It will upon inspection be seen that the number increases with the number of lines of the exchange. This is attributed to the fact

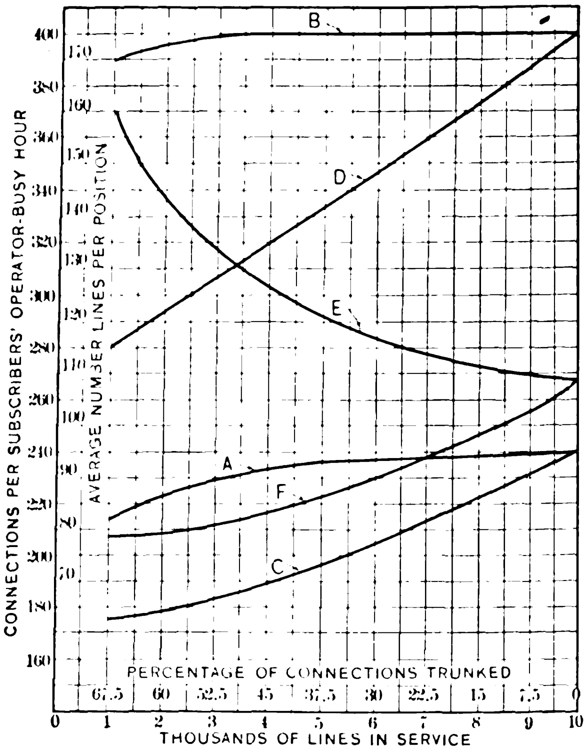

FIG. 2

Curve A shows average number connections (busy hour) per operator, in a single office manual exchange of from 1,000 to 10,000 lines.

Curve B shows average number connections (busy hour) per operator, in a single office automatic call distributing exchange of from 1,000 to 10,000 lines.

Curve C shows average number connections (busy hour) per operator, in a multi-office manual exchange of 10,000 lines (18 calls per line per day) when certain percentages of calls are trunked.

Curve D shows average number connections (busy hour) per operator, in a multi-office automatic call distributing exchange of 10,000 lines (18 calls per line per day) when certain percentages of calls are trunked.

Curve E shows average number lines per operator's position in a single office manual exchange of from 1,000 to 10,000 lines.

Curve F shows average number lines per operator's position in a multi-office manual exchange of 10,000 lines (18 calls per line per day) when certain percentages of calls are trunked.

that in the smaller exchanges the operators are less efficient and that the fewer the number of calls per line per day the less the regularity with which the calls originate, which results in a greater number of idle periods.

From curve *A* of Fig. 2 has been plotted the curve *E* of Fig. 2 which illustrates in single office exchanges varying from 1,000 to 10,000 lines the number of lines per operator's position, when the number of calls per line per day varies from $10\frac{1}{2}$ in 1,000 line offices to 18 in 10,000 line offices. It may be observed that although in the larger exchanges an operator can establish a greater number of connections per hour, nevertheless the number of lines allotted as calling lines to each operator is decreased, owing to the fact that the number of calls per line per day is increased.

Curve *C*, Fig. 2, sets forth the average number of connections an operator can establish in multi-office exchanges of 10,000 lines, at 18 calls per line per day,—when various percentages of calls are trunked,—during the busiest hour.

The percentage of calls trunked from any office has been arrived at by application of the formula

$$\text{Trunking per cent} = 100\,\frac{A-B}{A}\,0.75$$

wherein *A* is the total number of lines in the exchange, *B* the number of lines in the office under consideration and 0.75 is a factor which allows under ordinary conditions for the community of interest between the subscribers of the office. It is obvious, under the conditions assumed, that the greater the percentage of calls trunked, the fewer calls an operator can establish during the busy hour.

From curve *C* of Fig. 2 has been plotted curve *F* of Fig. 2, which sets forth the average number of lines which may be assigned to each operator in a multi-office system operated under the conditions of curve *C*, Fig. 2.

As there is not in commercial use an exchange operating under the automatic call distributing system, I have of course been unable to ascertain the actual number of calls an operator could establish during the busiest hour, but have assumed that there will be required in a single office exchange, according to the curve of Fig. 1, nine seconds for the establishment of each connection, from which assumption I have plotted curve *B* which shows the average number of connections an operator can establish during the busy hour, by means of the automatic call distributing system.

Allowing seven seconds additional for each connection trunked, *i.e.*, 16 seconds for each trunked connection, I have shown by curve *D*, Fig. 2, the average number of connections an operator can establish in a 10,000-line multi-office exchange, in the busy hour, in offices varying from 1,000 to 9,000 lines when certain percentages of calls as shown are trunked. As mentioned in reference to curve *B*, this is estimated, owing to the fact it is impossible to obtain the information from actually working commercial exchanges.

The vast difference in the number of connections per operator per hour between the two systems appears abnormal, but it is believed a little thought will convince the reader that the conclusions are correct and will be borne out in commercial practice.

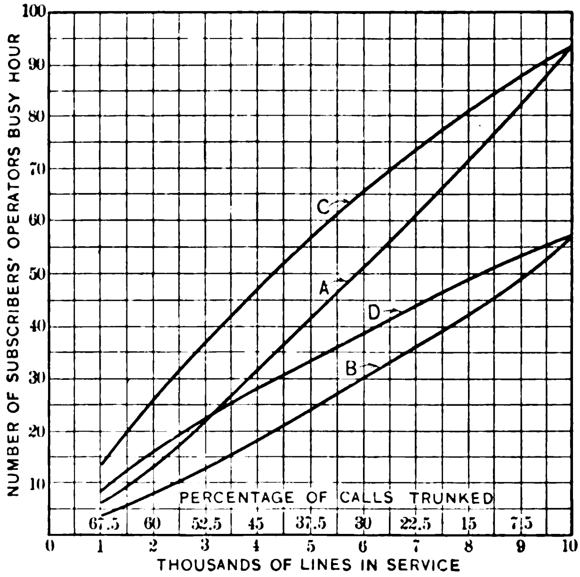

FIG. 3

Number subscriber's operators required during busy hour, as per Figs. 1 and 2.

Curve A represents single office manual system, 1,000 to 10,000 lines.

Curve B represents single office automatic call distributing system, 1,000 to 10,000 lines.

Curve C represents multi-office 10,000-line exchange, manual system, 18 calls per line per day.

Curve D represents multi-office 10,000-line exchange, automatic call distributing system, 18 calls per line per day.

Having arrived at the difference in number of calls per operator per hour, in each of the systems, it is next in order to consider the difference in the number of operators required to handle the traffic of the exchanges during the period of the peak of the load, *i.e.*, during the busiest hour. In order that this may be readily ascertained I have plotted the curves of Fig. 3, in which curve

A is based upon the results of the curve of Fig. 1 and curve *A* of Fig. 2 and shows the number of operators required to handle the traffic of a single office manual multiple switchboard system during the busiest hour. Likewise curve *B* of Fig. 3 is based upon the results of the curve of Fig. 1 and the curve *B* of Fig. 2 and shows the number of operators required to handle the traffic of a single office automatic call distributing system exchange during the busiest hour.

Curve *C*, Fig. 3, is plotted from curve *C* of Fig. 2 and shows the number of operators required, in a multi-office manual multiple switchboard exchange of 10,000 lines, at 18 calls per line per day, to handle the traffic of an office of a particular number of lines during the busiest hour when the percentages of connections, as shown, are trunked.

Curve *D* of Fig. 3 has been plotted from curve *D* of Fig. 2 and shows the number of operators required in a multi-office automatic call distributing exchange of 10,000 lines, 18 calls per line per day, to handle the traffic of an office of a particular number of lines when the percentages of connections as shown are trunked. The difference in number of operators in the two systems will, by inspection of the curves of Fig. 3, be apparent. As stated, the curves of Fig. 3 set forth the number of operators required during the busiest hour. It will, however, be understood by all traffic men that the number of operators required at all other hours of the day may be accordingly reduced.

Having ascertained the number of operators required for the operation of an exchange of given size, both single and multi-office, the annual saving in operators' wages and other costs incidental thereto may be readily ascertained. The saving is found to be at first glance almost inconceivable, but it is believed by the writer that the ratio will be approximately borne out in commercial practice.

While the automatic call distributing system has been well developed by at least one interest and it is understood also by others, the possible variations in the methods by which the result may be accomplished, three of which have been herein described, leave wide room for variation in the first cost of equipment for producing in exchanges of various sizes the operating results which I have set forth. It may be said that each of the outlined ways of accomplishing the results of automatic call distribution will maintain the advantages indicated by the curves.

In view of the possible wide differences in amount of equipment, depending upon the particular system preferred, and also for other reasons which a little thought will make apparent, it will be understood that the difference in relative percentage of first cost of manual systems and the automatic call distributing system will vary. The question of cost has, however, been given careful attention by the writer and figured out for a particular system. As a result I have plotted the curves of Fig. 4 which

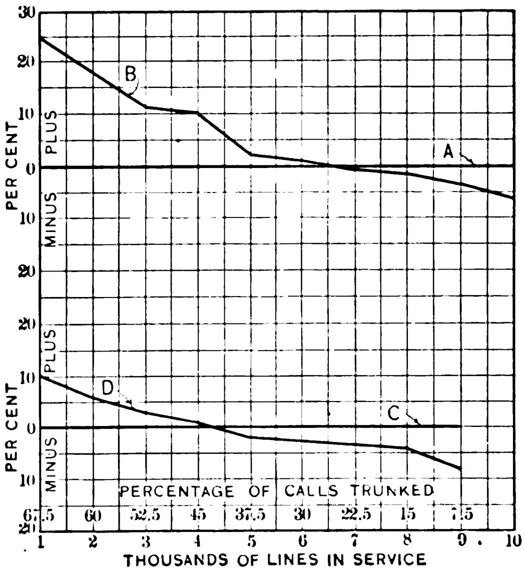

FIG. 4

Curves A and B represent percentage differences in cost of a single office exchange of from 1,000 to 10,000 lines. Curve A represents manual and curve B represents automatic call distribution.

Curves C and D represent percentage differences in cost of a multi-office 10,000-line exchange (18 calls per line per day) when certain percentages of calls are trunked. Curve C represents manual and curve D represents automatic call distribution.

are intended to show difference in percentages of first cost of all central office equipment with the exception of long distance equipment.

The curves *B* and *D* of Fig. 4 are not based on apparatus built for commercial use, but are estimated on what, in the opinion of the writer, the apparatus will cost installed.

Curves *A* and *B* of Fig. 4, wherein curve *A* represents manual and curve *B* automatic call distributing, are intended to show the percentage difference in first cost of the central office equipment, exclusive of long distance equipment, of single office exchanges varying from 1,000 to 10,000 lines, when the number of calls per line per day vary according to the curve of Fig. 1.

The curves *C* and *D* of Fig. 4, wherein curve *C* represents manual and curve *D* automatic call distributing, are intended to show, in multi-office exchanges of 10,000 lines, the percentage difference between the two systems in first cost of the central office equipment, except long distance equipment, of offices of the particular number of lines as shown, when the number of calls per line per day is 18, and when the percentage of connections as shown, are trunked.

An inspection of the curves will show the first cost in single office exchanges of the central office equipment of an automatic call distributing exchange of 6,750 lines or less to be greater than that of a manual exchange of equal number of lines, while for single office exchanges of a greater number of lines the first cost of the automatic call distributing becomes less than that of a manual exchange of like number of lines.

In multi-office 10,000-line exchanges operating under conditions hereinbefore set forth, the first cost of the central office equipment of the automatic call distributing system is less than that of the manual system, when the size of an office exceeds about 4,300 lines.

Thus from the above we find, under the conditions herein assumed, that the cost of operation of the automatic call distributing system is, for all sizes of exchanges, *less than that of manual multiple telephone switchboard system*, and that for the larger sized offices, *i.e.*, offices of the greater number of subscribers' lines, not only the cost of operation, but also the first cost of the automatic call distributing system is less than that of the manual system.

In considering cost of operation I have not so far taken into consideration the relative cost of maintenance. As the switches for accomplishing automatic call distribution are more complex than the central office apparatus used in the manual system, the cost of the maintenance of these switches will somewhat increase, in the writer's opinion, the total annual maintenance cost of the central office apparatus. But it must be understood that the amount of the apparatus which would be used in the manual system is decreased, when automatic call distribution is applied, the result being that the increased annual maintenance cost of the automatic call distributing system, owing to the selective switches, over that of the manual system, will be very slight; it may in fact be considered negligible, when compared with the great saving in operators' expense.

What I have hereinbefore stated has had reference particularly to new installations of central office equipment. Before concluding the discussion I will state that automatic call distribution may with economy be applied to existing exchanges. As an example, considering a single office exchange of say 6,000 lines, it is found by reference to curve *A*, Fig. 3, that without automatic distribution approximately 51 operators are, during the busiest hour, required to handle the traffic, while with automatic call distribution with the same number of operators, (see curve *B* of Fig. 3) the traffic of approximately 9,300 lines may be handled during the busy hour. Thus by installation of the automatic call distribution apparatus and the necessary multiple jack terminals for the number of lines over and above 6,000 lines, the number of lines of the exchange may be increased approximately 55 per cent. Thus with only the number of operators necessary to handle the traffic of the original 6,000-line manual exchange, the traffic of an exchange of 9,300 lines may be handled. The cost of additional equipment necessary to accomplish this result, it is believed, would not be greater than the cost of the equipment necessary to increase a manual exchange from 6,000 to 9,300.

Or, if it is not desired to increase the number of lines of the exchange, the cost of operation may be reduced by the installation of the apparatus necessary for automatic call distribution, and it is believed that the decrease in cost of operation will be much greater than the interest on the additional investment and the additional cost of maintenance of the automatic call distribution apparatus.

Another manner in which automatic call distribution may be applied to existing exchanges is to install equipment necessary to handle the traffic during the busiest hour with automatic call distribution apparatus and thereafter, by dividing the switchboard including the multiple equipment, utilize the positions not then required, as a separate switchboard, which may then be equipped with the automatic call distribution apparatus and by installation of trunking apparatus and circuits, the exchange may be converted into a multi-office of a greater number of lines. The increase in number of lines will depend upon the number of operators' positions of the original equipment saved by the change.

Either of the above changes from the manual system to the automatic call distribution system can be accomplished without impairing in any manner the efficiency of service, as the change may be made on each position of the switchboard and on each line without disturbing in any manner the other positions or lines of the office.

None of the above could be accomplished if it should be attempted to change from the manual multiple switchboard system to any other system other than the automatic call distribution system.

Should the attempt be made to change an existing manual exchange to an automatic exchange, not only would the numbers of the substations of all the lines have to be changed, requiring a new directory and confusion on the part of subscribers, but all of the telephones would have to be changed or replaced and an entire new switchboard provided, incurring enormous expense in addition to confusion and probable dissatisfaction in service.

Should the attempt be made to change an exchange from a manual multiple switchboard system to the so-called "auto-manual" system, the same confusion in reference to change in numbers on the part of the subscribers would be present, and in addition it would mean the installation of a new switchboard equipment of apparatus of greater amount and complexity than would be required even in a full automatic system.

A telephone company has but two objects—to give satisfactory service to its subscribers and a reasonable return to its stockholders on the capital invested.

In accordance with all that has been said, it is firmly believed by the writer at this time, that—excepting possibly the largest exchanges—when all items of expense are considered, and especially in reference to existing manual exchanges, the automatic call distribution, as herein explained, will be found to be more economical and satisfactory than any other known telephone system adapted to give satisfactory service to its subscribers.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April, 16-20, 1912.

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(Subject to final revision for the Transactions.)

PLANT EFFICIENCY

AN ANALYSIS OF THE LOSSES OF A HYDROELECTRIC SYSTEM

BY J. D. ROSS

The following paper is an analysis of the losses and efficiencies of the Seattle Municipal Light and Power plant for the year 1911.

Great care has been taken in these measurements and the results have been checked in as many ways as possible and instruments have been frequently calibrated. These figures are therefore believed to be a close approximation to the true values.

GENERAL DESCRIPTION OF PLANT

The Seattle plant is a hydroelectric system delivering water to two 1,500 kw. Pelton units and two 5,000 kw. turbine units under 600-ft (183 m.) head through two pipes approximately 3½ miles (5.6 km.) long, one of which is 67¾ (172 cm.) and the other 49 (124 cm.) inside diameter. The current is transmitted at 60,000 volts through two lines to Seattle, a distance of 38.7 miles (62.2 km.), and is there distributed at 15,000 and 2,400 volts for use by approximately 20,000 customers and for the city street lighting.

Pipe Lines and Penstocks. The 67¾-inch (172 cm.) pipe consists of 15,865 ft. (4,835.6 m.) of wood stave pipe dividing at a point 951 ft. (289.8 m.) from the power house into two 48-in. (122 cm.) riveted steel penstocks. The 49-in. (124 cm.) wood pipe joins onto a 48-in. (122 cm.) riveted steel penstock at a point 1,008 ft. (307.2 m.) from the power house.

Careful tests were made on the 67¾-in. wood stave pipe, using gages calibrated before and after. The pipe contains five steel elbows, where the curvature is greater than 20 deg. These elbows are made to a 15-ft. (4.57 m.) radius and have angles respectively 92, 55, 60, 65, and 45 degrees. The loss in head of each elbow was measured by a differential pressure gage. The results of the test are given in detail in the following table:

LOSS OF HEAD IN FEET IN VARIOUS PARTS OF 67¾-IN. (172 CM.) WOOD STAVE PIPE

Velocity in ft. per second	Loss in entry and screens	Elbow No. 1 92°	Elbow No. 2 55°	Elbow No. 3 60°	Elbow No. 4 65°	Elbow No. 5 45°	Total loss in pipe	Friction loss after deducting entry and elbows	Loss in 67¾" stave pipe per 1,000 feet	Value of C. in Kutters formula	Value of N. in Kutters formula
2½	.06	.03	.03	.03	.03	.01	4.1	3.91	.246	134.06	.01190
5	.25	.09	.08	.08	.08	.05	15.4	14.77	.931	137.96	.01175
7½	.54	.25	.18	.19	.20	.14	33.9	32.40	2.0425	139.71	.01165
10	1.14	.46	.34	.36	.37	.27	61.9	58.96	3.775	137.01	.011865

NOTE: 1 ft. = 0.3048 in.

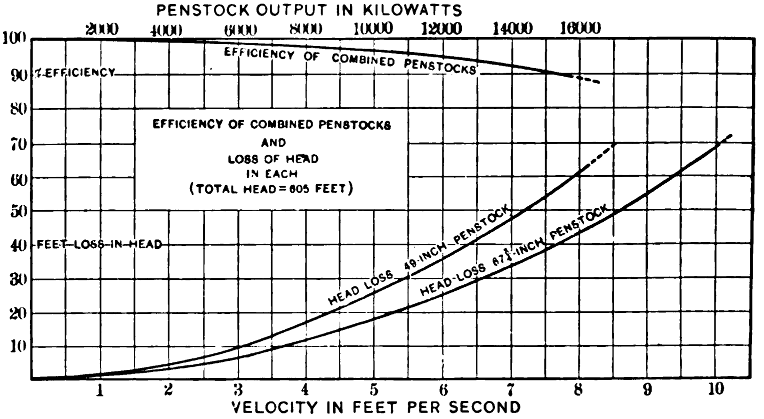

FIG. 1

This pipe has been in operation since November 20, 1908. The loss in entry as given in the above table seems large and rises with the velocity more rapidly than it should. This is apparently due to the resistance of the screens, which are of wood bars. These were being changed before the test was made as it was noticed at times of heavy load that there was a difference of level on the two sides of the screens. The entry of the pipe is bell-mouthed. The total length of the wood pipe is 15,865 ft. (4,835.6 m.) The line was designed for a slope of four feet per thousand feet to give a velocity of ten feet (3.05 m.) per second.

The loss in the penstocks was computed from records taken by Bristol recording gages at the generating station, which were frequently calibrated. The results so obtained were checked by computing the loss from the efficiency shown under test, and agreed very closely. The maximum output of the two penstocks was 12,400 kw., with a loss of 6 per cent, and the average output for the year was 6,009 kw., with an average loss of 2.3 per cent. This loss was increased by the fact that the plant was supplied for thirty-three days in November and December by the larger pipe alone.

Generating Station. There are four units in the power house, two of which consist of 8,000-h.p. Francis turbines direct-connected to 60-cycle, 2,300-volt, three-phase generators rated at 4,000 kw. at 35 deg. cent. rise, with a four hour overload capacity of 5,000 kw. at 40 deg. cent. rise. These units operate at 600 rev. per min. The other two units are driven by 2,400-h.p. Pelton impulse wheels direct-connected to 60-cycle, 2,300-volt, three-phase generators rated at 1,200 kw. at 35 deg. cent. rise, with a four hour overload capacity of 1,500 kw. at 40 deg. cent. rise. These units operate at 400 rev. per min. The wheels are each equipped with two runners, each of which is supplied from a needle and a deflecting nozzle. The combined capacity of the present installation is therefore 13,000 kw. on a 40 deg. cent. rating. The two machines last mentioned, however, exceed their rating and have been operated continuously without excessive heating at 1,750 kw., making the combined capacity 13,500 kw. Three water wheel exciter units are installed, two of which have a capacity of 75 kw. each, and the third 150 kw.

As the efficiency of each unit varies with the load, and it is obviously impossible to have all generators that are in use at any time carry their full load, the all-day efficiency of the generating station will depend on the number of units in use and the load which each carries, as well as on the power factor of the load and, in the case of this plant, where two types of wheels are used, it will also depend on the proportion of the load that the operator gives to each type of machine. In general, the greatest all-day efficiency can be had by keeping the machines as nearly as possible at the load of maximum efficiency, and by shutting down the machines without load as far as can conveniently be done.

While the combined maximum efficiency of generator and wheel was found in the case of the 5,000 kw. units to be 76.7

per cent, and in the case of the 1,500-kw. units to be 69.9 per cent, the all-day efficiency of the plant for 1911 was found to be 56.7 per cent. This does not include current for excitation and station lighting. By including this as a loss, the all-day efficiency of the plant drops to 55.7 per cent.

The reason for the difference in the same type of unit is found in the fact that the operators favor No. 1 and No. 4 machines, from habit rather than intention. The impulse wheels, being small, are operated under full load for a great part of the day and their all-day efficiency is greater than that of the turbines, notwithstanding the higher efficiency of the turbine sets at full load. It will be readily seen from these facts that the efficiency of a plant depends very largely on the way it is handled by the operator and during low water periods it is possible to prepare a schedule showing which machines should be used for each load which the plant carries. This schedule will be modified by the conditions of the plant, changes in load, and regulation.

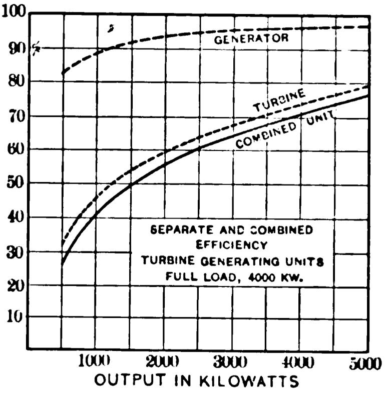

FIG. 2

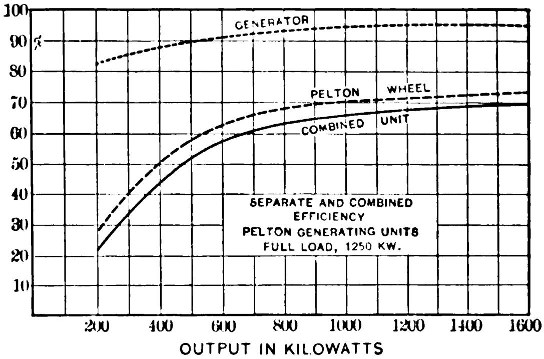

FIG. 3

Losses in the water wheels and generators were computed from the half-hour wattmeter readings on the generators as recorded in the station report. The input for each output throughout the year was computed from efficiencies shown in tests made in 1909 and checked at the end of 1911. The results show all-day efficiencies for the year as follows:

EFFICIENCY

	Wheel	Generator	Combined
Impulse Unit No. 1	70.8	93.0	65.8
Impulse Unit No. 2	66.3	92.2	61.1
Turbine Unit No. 3	57.1	93.0	53.1
Turbine Unit No. 4	63.6	94.1	59.8
Four units combined	60.7	93.5	56.7

The higher efficiency of the impulse units is due to the fact that they were nearly always loaded above 900 kw. and the regulating was done with the relief valves and governors on the turbines, so that there was little loss from the deflecting nozzles.

The power used in excitation was computed from the half-hour readings on the exciter outputs, and amounted to 399,120 kw-hr. or 1.3 per cent. of the output of the generators. The water input to the exciter units, computed similarly to that of the large units, was 665,200 kw-hr. Station lighting, including light for the employees' cottages, amounted to 175,000 kw-hr. for the year.

Step-Up Transformers. The station is equipped with nine transformers. Each bank of three has a normal capacity of 4,500 kw. at 35 deg. cent. temperature rise. These transformers step the voltage from 2,300 to 60,000 volts three-phase star connected. The neutral of the star connection is grounded. The manufacturers were requested to sacrifice efficiency for high insulation, if necessary, but the efficiency is found to be as high as is customary when using lower insulation. These transformers were all in circuit continuously to keep them in good condition, and their core losses were practically constant, amounting to 926,000 kw-hr., or an average of 11.7 kw. per transformer. The copper loss was computed from the readings on the reports, and

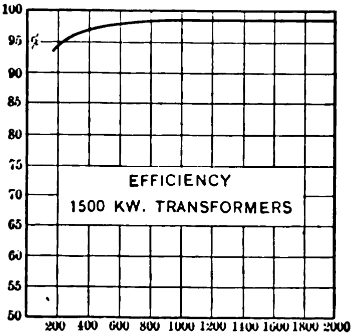

FIG. 4

amounted to 200,00 kw-hr. or an average of 2.54 kw. per transformer.

	Kw-hr.	Average kw.
Core loss	926,000	106
Copper loss	200,000	23
Total loss	1,126,000	129
All-day efficiency	96.1 per cent.	

High-Tension Lines. There are two high-tension lines 38.7 miles (62.2 km.) in length strung on two different makes of insulators of practically the same size and type. One of the lines is of No. 2 solid medium hand-drawn copper, the wires being placed in a six-foot (1.83 m.) triangle. The other is built of No. 0000 seven-strand hard-drawn copper, the wires being placed in a seven-foot (2.13 m.) triangle.

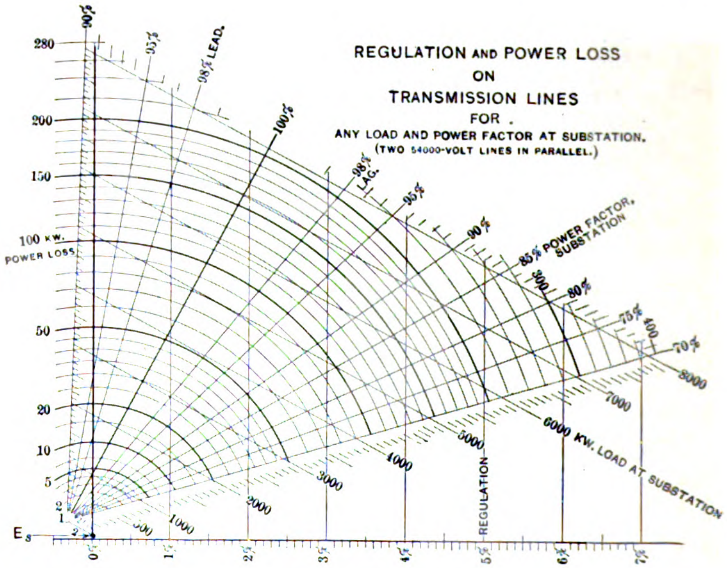

FIG. 5

The line loss was computed from the constants of the lines, taking the load data shown by the report sheets. The line resistances were measured by direct current, using the fall of potential method, and agreed very closely with the computed value. The inductance and capacity were calculated from the values given in the Standard Handbook, third edition. To simplify calculation for the all-day efficiency, a Perrine-Baum regulation diagram was drawn for both lines in parallel. To this were added circles, taking as a center the end of the substation voltage vector, and as a radius the square of the voltage drop in the line, multiplied by the conductance of the line. The radii of these circles represent power loss. The power lost during 1911 on the two lines, figured from this diagram, using the half-hour readings at the substation for load data, amounted to 378,000 kw-hr. or an average of 43 kw. for the year.

	Kw-hr.	Average kw.
Line loss	378,000	43
All-day efficiency	98.6 per cent.	

Step-Down Transformers. The step-down transformers are placed on the first floor of the substation. There are at present eight of these, each of 1,500 kw. capacity at 35 deg. cent. temperature rise. All are made with a ratio of 54,000 volts, three-phase to 15,000 and 2,500 Scott connected two-phase, making four banks of transformers. The low-tension coils are connected in series for 15,000 and in multiple for 2,500 volts, two banks being used on each voltage.

The step-down transformer loss, computed in the same way as that of the step-up transformers, was as follows:

	Kw-hr.	Average kw.
Core loss	692,000	79
Copper loss	217,500	25
Total loss	909,500	104
All-day efficiency	96.6 per cent.	

The sum of the losses in line and transformers was checked against the difference in the watt-hour meter readings on the low-tension side of the transformers at each end of the line, and was about five per cent lower. This may not have been due to error but may be largely due to corona loss or other line leakage. No measurements have as yet been made to determine this point.

Main Substation. The main substation contains the step-down transformers, a distributing switchboard of the remote control type, and the necessary switching and control apparatus for the distributing feeders. The switchboard carries a complete set of curve-tracing meters for the high-tension lines, indicating ammeters and wattmeters and watt-hour meters for the transformers, and indicating ammeters, recording voltmeters and watt-hour meters for the feeders. Loss in meters and their instrument transformers was computed from tests made on each type of meter and transformer. Current used for station light, heat and display lighting was metered.

	Kw-hr.	Average kw.
Loss in meters	29,000	3
Power for station light	317,400	37
Total loss	346,400	40
All-day efficiency	98.7 per cent.	

Motor-Generator Set. A motor-generator set consisting of a 750-h.p., two-phase synchronous motor direct-connected to two 250-kw. 250-volt direct-current compound-wound generators is used on a three-wire 500 and 250-volt system for operating elevators and other motors. The maximum load on this machine at the present time on the direct-current side is 300 kw. and the average load for 1911 was 30.2 kw. The surplus kilovolt-ampere capacity of the motor is utilized in regulating the voltage of the main system by varying the power factor by means of a Tirrill regulator controlling the field of the motor. There are at present 71 services connected on this system with a connected load of 772½ h.p. The main feeder is 750,000-cir. mil cable with a 400,000-cir. mil neutral, and the branches usually No. 4/0 with No. 2/0 neutral. In all, 27 miles (43.4 km.) of wire are used on this system.

The total loss in the direct-current feeders and the motor-generator was obtained from the difference in the motor watt-hour meters and the customers' meters. From recording voltmeter charts taken at various distributing points and at the substation and from computations, using the load data and line resistance, the line loss is placed at 5 per cent. The details of losses and efficiencies follow:

	Efficiency, 1911	Loss, kw-hr.	Average loss, kw.
Motor-generator	38.	417,000	48
Direct-current lines	95.0	12,800	1
Customers' meters	98.8	3,000	..
Total direct-current system	35.7	432,800	49

15,000-*Volt System.* Current is distributed at 15,000 volts from the main substation to two smaller substations and to about twelve mills and factories which use large amounts of power. This system is two-phase, with the center point of each phase grounded. For mechanical reasons, No. 2 is the smallest wire used on the 15,000-volt lines. There are about 105 miles (169 km.) No. 2, nine miles (14.5 km.) of No. 1, and two and one-half miles (4.02 km.) of No. 0 wire. There are 30 transformers connected, ranging in size from 750 kw. to 50 kw., with a combined capacity of 6,250 kw.

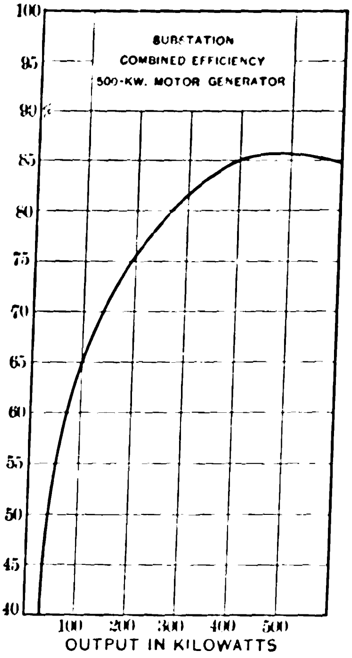

FIG. 6

Loss in the 1,500-volt system was found by taking the difference in the meter readings at substation and at the various receivers, and checked closely by calculation from the line constants and load data. The transformer losses on this system were computed from the load data on the station reports and the tests taken on each size and type of transformer under actual operating conditions.

Copper loss is small compared to core loss because the transformers were lightly loaded; an installation of 6,250 kw. carried an average load of 1,323 kw. The detail losses were:

	Efficiency, 1911	Loss, kw-hr.	Average loss, kw.
15,000-volt lines	99.2	93,500	11
15,000-volt transformers	93.2	775,100	88
Core loss		694,000	79
Copper loss		81,100	9
Total for system	92.5	868,600	99

2,400-*Volt Distributing System.* Power is distributed from the substations by means of seventeen 2,400-volt primary feeders. Of these, twelve are fed from the main substation at Seventh Avenue and Yesler Way, three from Fremont substation and two from West Seattle substation. The more heavily loaded circuits were designed for 200 amperes and the lighter ones for 150 amperes. Number 4/0 wire was used at first, but the economic size for a 200-ampere feeder has been computed at 350,000 cir. mils, which size is now used on the heavier feeders.

An area of 28 square miles (72.5 sq. km.) is served by this system extending seven miles (11.2 km.) south and six miles (9.6 km.) north of Yesler Way. A distributing point is established at the approximate center of distribution for each feeder, and the automatic regulators in this station are set to give the desired voltage at this point.

Connected to the 2,400-volt feeders are 1,082 distributing transformers, ranging in size from 2½ kw. to 50 kw., and with an aggregate full-load capacity of 9,268½ kw. They are connected to give a 240-120-volt three-wire low-tension winding, with the neutral grounded. To aid regulation, a number of transformers of the same size and type are usually connected together on the low tension side where conditions will permit. The secondary wire is generally No. 4 for the outside wires and No. 6 for the netural, with No. 8 for the services. The maximum voltage drop from transformer to customer is kept within 2 volt whenever possible, since there is no way of regulating for voltage between these points. The pressure at the service is kept as near 120 volts as possible. Although standard 2,200-110-volt transformers are used, the pressure has been raised to 2,400 volts, and it is planned to raise it still further to 2,500 volts. This gives about 25 per cent higher core loss, but lowers the copper loss in both transformers and feeders about 29 per cent, and in addition gives nearly 14 per cent better regulation. The 2,400-volt system used 545.4 miles (877.7 km.) of high-tension wire, ranging in size from No. 6 to 350,000 cir. mils, and 1,137.7 miles (1,830.9 km.) of low-tension wire, varying from No. 6 to No. 4/0.

Losses in the feeder regulators were computed from tests made on each type used, in conjunction with load data from the station reports. Losses in distributing transformers were computed in the same way, using also recording ammeter charts taken at distributing points. Losses in the high-tension line were computed from the load data and line resistances of each feeder, and checked by recording voltmeter charts taken at the station and at each distributing point. Loss in low-tension line was estimated from line resistances and load data, and checked by recording voltmeter at the customers' services. Loss in the customers' meters was computed from tests on each type of meter in use.

A check on the various distributing losses is furnished by the difference in the power metered to the customer and that delivered to the distributing system. This amount proved to be slightly greater than the sum of the losses as computed, and the difference was added to the loss in low-tension system, since that loss was most difficult to determine with accuracy. There is also probably a small amount of stolen current included in the low-tension loss. The details of losses on the 2,400-volt commercial system follow:

	Efficiency, 19	Loss, kw-hr.	Average loss, kw.
Feeder regulators	98.6	178,500	20
Primary feeders	96.0	521,600	60
Distributing transformers	88.8	1,391,000	159
Core loss		960,000	110
Copper loss		431,000	49
Secondaries	92.9	782,600	89
Customers' meters	97.6	250,000	29
Total for system	76.2	3,123,700	357

Cluster Light System. The cluster light system comprises 1,631 poles, lighting 25 miles (40.2 km.) of street and carrying 6,851 lamps of a total of 335,700 watts. This system is supplied from 720 kw. in transformers using 23 miles (37 km.) of primary wire carrying 2,400 volts and 98.4 miles (158.3 km.) of secondary wire in a 240- and 120-volt three-wire system. The voltage is changed from 120 volts to 8 volts in the base of the pole and 8-volt multiple lamps are used. Losses on this system were computed in a similar manner to those on the other distributing systems. They lack the check of integrating meters at the lamp, but were easier to compute on account of the constancy of the load. The transformer losses contain those from the pole-base transformers, which are 250-watt, 8-volt transformers.

	Efficiency, 1911	Loss, kw-hr.	Average loss, kw.
Cluster light primaries	97.0	42,500	5
Cluster light secondaries	93.0	86,500	10
Cluster light transformers	87.8	181,000	21
Core loss	....	117,500	13
Copper loss	....	63,500	7
Total for system	79.1	310,000	35

Series Street Lighting System. The series street light system comprises 683 miles (1,099 km.) of No. 6 wire divided into 29 circuits, lighting 601 miles (967.2 km.) of street. The circuits are connected two in series to 100-light air-cooled constant-current transformers. The voltage on the circuits varies with the number and kind of lamps from 2,500 volts to 5,000 volts. Altogether there are 692 6.6-ampere arc lamps, 5,315 40-candle-power tungsten lamps, and 199 300-candle-power tungsten lamps.

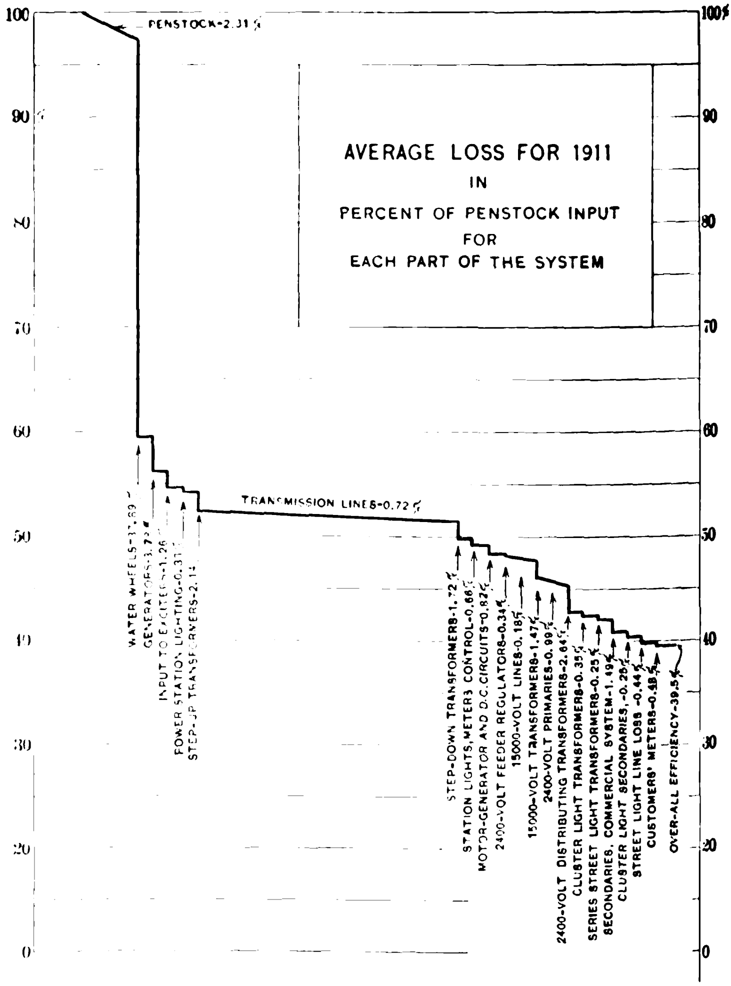

FIG. 7

OUTLINE OF LOSSES AND EFFICIENCIES FOR 1911, SEATTLE MUNICIPAL LIGHT AND POWER PLANT.

	Per cent all-day efficiency	Total 1911 input, kw-hr.	Average 1911 input, kw.	Total 1911 loss, kw-hr.	Average 1911 loss, kw.	Per cent loss	Per cent of penstock input	Per cent of total loss
GENERATING SYSTEM	54.4	52,639,000	6009	23,990,300	2739	45.6	45.6	75.3
Penstocks	97.7	52,639,000	6009	1,214,900	139	2.3	2.3	3.8
Generating station	55.7	51,424,100	5870	22,775,400	2600	44.3	43.2	71.5
Water wheels	60.7	50,758,900	5795	19,944,400	2277	39.3	37.9	62.6
Generators	93.5	30,814,500	3518	1,990,800	227	6.5	3.8	6.2
Exciters	....	665,200	76	665,200	76	....	1.3	2.1
Station lights and control	....	175,000	20	175,000	20	....	0.3	0.5
TRANSMISSION SYSTEM	91.6	28,648,700	3270	2,413,500	276	8.4	4.6	7.6
Step up transformers	96.1	28,648,700	3270	1,126,000	129	3.9	2.1	3.5
Transmission lines	98.6	27,522,700	3141	378,000	43	1.4	0.7	1.2
Step-down transformers	96.6	27,144,700	3098	909,500	104	3.4	1.7	2.9
DISTRIBUTING SYSTEM	79.2	26,235,200	2994	5,448,700	622	20.8	10.3	17.1
City substation	98.7	26,235,200	2994	346,400	40	1.3	0.7	1.1
S. Lights and control	....	317,400	37	317,400	37	1.2	0.6	1.0
Switchboard meters	....	....	....	29,000	3	....	0.1	0.1
15,000-volt system	92.5	11,587,000	1323	868,600	99	7.5	1.6	2.7
15,000-volt lines	99.2	11,587,000	1323	93,500	11	0.8	0.2	0.3
15,000-volt transformers	93.2	11,493,500	1312	775,100	88	6.8	1.5	2.4
Series street lights	86.3	2,672,800	305	367,200	42	13.7	0.7	1.2
Transformers	95.0	2,672,800	305	133,700	15	5.0	0.3	0.4
Series circuits	90.8	2,539,100	290	233,500	27	9.2	0.4	0.7
Cluster street lights	79.1	1,486,000	170	310,000	35	20.9	0.6	1.0
Cluster transformers	87.8	1,486,000	170	181,000	21	12.2	0.3	0.6
Underground cables	90.1	1,305,000	149	129,000	15	9.9	0.2	0.4
2400-volt commercial system	76.2	13,178,400	1612	3,123,700	357	23.8	5.9	9.8
Feeder regulators	98.6	13,178,400	1612	178,500	20	1.4	0.3	0.6
Primary feeders	96.0	12,999,900	1592	521,600	60	4.0	1.0	1.6
Transformers	88.8	12,478,300	1532	1,391,000	159	11.2	2.6	4.4
Secondaries	92.9	11,087,300	1373	782,600	89	7.1	1.5	2.5
Customers' meters	97.6	10,304,700	1284	250,000	29	2.4	0.5	0.8
Direct-current system	35.7	673,200	77	432,800	49	64.2	0.8	1.4
Motor-generator	38.0	673,200	77	417,000	48	62.0	0.8	1.3
D-C. circuits	95.0	256,200	29	12,800	1	5.0	....	....
Customers' meters	98.8	243,400	28	3,000	....	1.2	....	....

SUMMARY: Total power loss..........................31,852,500 kw-hr. Average 3,636 kw.
Total power delivered to customers..........................17,304,900 " " 1,975 "
Total power delivered to street lamps..........................3,481,600 " " 398 "
Total delivered power..........................20,786,500 " " 2,373 "
Over-all efficiency, 39.5 per cent.
[1 kw-hr. at the customers' premises requires 1,364 gallons (5,163 liters) of water from Cedar Lake at average head of 590 feet (179.8m.)].

Losses were computed in a similar manner to those on the cluster light system, and were as follows:

	Efficiency, 1911	Loss, kw-hr.	Average loss, kw.
Series lines	90.8	233,500	27
Constant current transformers	95.0	133,700	15
Core loss	....	63,900	7
Copper loss	....	69,800	8
Total for system	86.3	367,200	42

The table on the preceding page, shows the losses and efficiencies for each part of the system, and the accompanying diagram shows each loss expressed in per cent of penstock input.

The writer is indebted for very considerable assistance from Dr. C. E. Magnusson and Prof. Harris of the University of Washington in tests on pipe lines and generating units, and to Mr. Glen Smith of the City Light Department of Seattle for compilation of tests and data.

The generators and station transformers were also tested by the Electrical Testing Laboratories of New York.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16–20, 1912.

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(Subject to final revision for the Transactions.)

DESIGN OF TELEPHONE POLE LINES FOR CONDITIONS WEST OF THE ROCKY MOUNTAINS

BY A. H. GRISWOLD

One of the most important portions of the outside plant of the companies engaged in the transmission of energy or intelligence is the structure for supporting the conductors, and as such it is receiving a constantly increasing consideration from engineers, as the value of an uninterrupted service at the least cost is being realized.

Of the companies using pole lines in the states west of the Rocky mountains, the Pacific Telephone and Telegraph Company undoubtedly has the most invested, encounters the greatest diversity of conditions, and covers more territory than any other company. For these reasons, this article will be devoted largely to the practises of this company.

WEATHER CONDITIONS

One of the most important factors in the design of pole lines is the variation in weather conditions, and in the region under consideration these conditions range from the mildest to the most extreme.

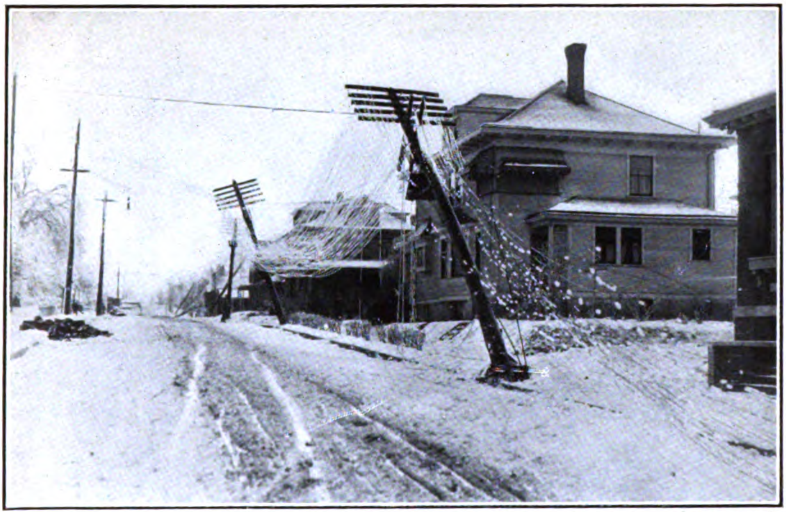
In Oregon and Washington, the destructive " pogonit " and " silver thaw " occur. The former is a weather condition encountered near Spokane, Wash. The word " pogonit " is an Indian name given heavy fogs which drift inland and freeze on cold exposed surfaces. The accumulation of ice on the wires sometimes to a diameter of about four in. (10 cm.) frequently causes complete failure, especially when followed by winds of high velocity.

The "silver thaw," while in many respects similar to sleet storms encountered in other parts of the country, is a name applied to a peculiar condition existing in Portland, Ore., and the near vicinity. Portland is situated at the junction of the Willamette and Columbia rivers. The winter climate of the Willamette valley is temperate while that of the Columbia valley is very severe. A very cold east wave passes down the Columbia valley and settles over Portland. This wave is usually of a temperature of from 5 to 22 deg. fahr. A southerly wind from the Willamette valley then sweeps the moisture laden clouds toward Portland, the clouds being deflected to the upper strata by the hills south of the city and over the cold air from the east. Precipitation then starts from the upper strata; freezing in passing through the cold lower strata and crystallizing on all solid objects. This condition has occurred in the past on an average of every four years since 1871 (before which time no records were kept). During this period, however, there have been only three storms which have been severe, those of 1881, 1907 and 1912. During the last storm all aerial plant in Portland was coated with from one-half to one in. (13 to 25 mm.) of solid ice. (See Figs. 1A and 1B).

On the Coast range and high Sierras, high winds, low temperatures, sleet and great depth of snow are experienced. In some portions, such as at Summit, Cal., the Government records show the annual average snowfall to exceed 36 ft. and (10.9 m.) occasionally the annual fall exceeds 65 ft. (19.8 m.) During long-continued storms the snow sometimes reaches a depth sufficient to cover the entire pole line, (see Fig. 2), burying it under many tons of snow, and during subsequent changes of weather conditions, a crust forms and gradually sinks, crushing the whole Lne by sheer weight.

In the southeastern portion of California, embracing the territory of the San Bernardino and Colorado Deserts, one of the highest ranges of temperature in the United States occurs. Government records show that the annual range of temperature in that region varies from the freezing point to over 130 deg. fahr. A temperature of over 140 deg. has been reported. Such great temperature changes make it necessary to exercise great care in stringing the conductors. An exact relation between sag and temperature must be maintained to prevent dangerous stresses arising during subsequent falls in temperature.

On the mountains bordering the Pacific coast, and especially along certain exposed portions of the coast, high winds are



[GRISWOLD]

FIG. 1A.—EFFECT OF SILVER THAW, PORTLAND, OREGON, 1912, ON OBSOLESCENT POLE CONSTRUCTION

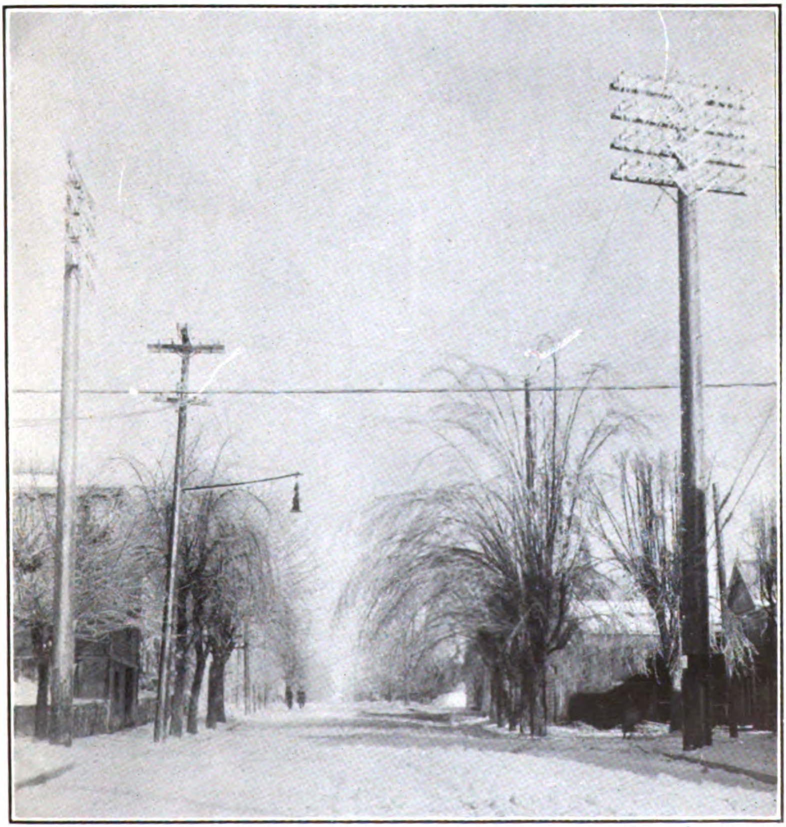


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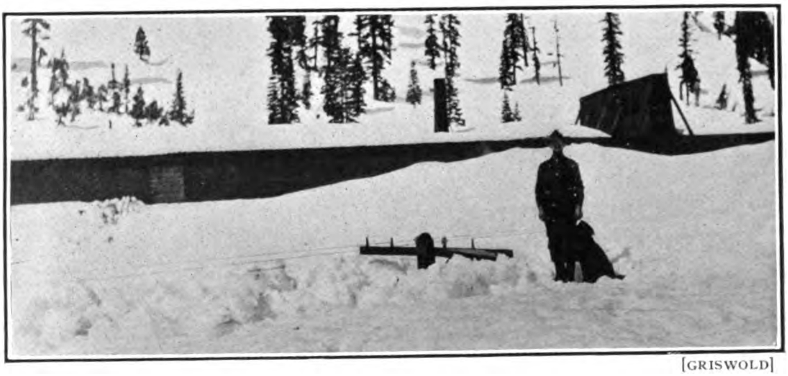
FIG. 1B.—EFFECT OF SILVER THAW, PORTLAND, OREGON, 1912, ON MODERN STANDARD TOLL LINE CONSTRUCTION



[GRISWOLD]

FIG. 2.—HEAVY SNOWFALL AT CISCO, CAL., SHOWING SAN FRANCISCO-RENO TOLL LEAD AND SOUTHERN PACIFIC SNOW SHEDS

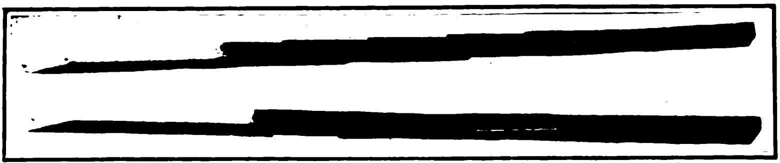


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FIG. 3.—SHOWING EROSIVE ACTION OF SAND STORMS

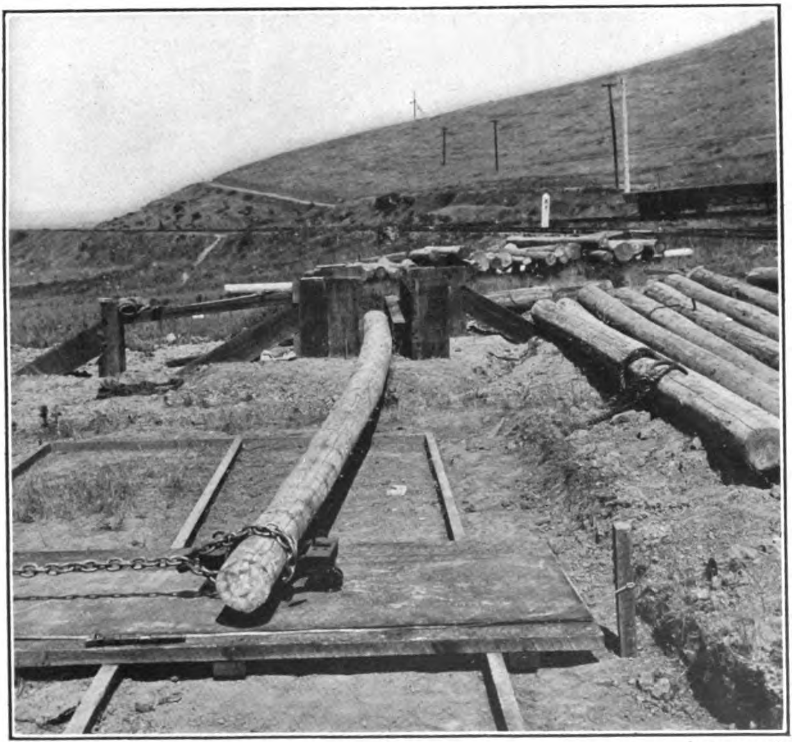

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FIG. 4.—GENERAL VIEW OF TESTING APPARATUS

encountered. On the eastern edge of the mountains bordering the western side of Death Valley and the Salton or Colorado Desert, the winds often reach the magnitude of a hurricane. High velocities are recorded annually during the months from October to March. Along the entire coast, and throughout the larger portion of Southern California, weather conditions of unusual mildness prevail. It is evident, therefore, that weather conditions as severe as any in the United States, as well as the most mild conditions, must be met in the design of pole lines.

POLES

Supply. Of the available supply of timber existing in any quantity west of the Rocky mountains, but three kinds are suitable for poles in the untreated form—Western red cedar, (*thuja plicata*) commonly known as Western white cedar, redwood (*sequoia sempervirens*), and Port Orford cedar or Lawson cypress, (*chamaecypris Lawsoniana*). Due to the limited supply of the Port Orford cedar, it is not of much importance, notwithstanding its virtues. When open-tank or pressure preservative treatment becomes general, the field of available pole timber will be much widened by the use of such woods as lodgepole, pine, yellow pine, Douglas fir, tamarack and other conifers.

With a few exceptions, redwood is used for poles only in the sawn form, and since redwood is used very extensively for structural purposes, the price depends upon the market price of redwood lumber, which fluctuates considerably. Unlike redwood, which is sawn from very large trees, cedar is generally used in its natural form. Inasmuch as the demand for poles is probably much more uniform than for lumber, and also because of the fact that the greater portion of the timber used for poles would be of little value for other purposes, the price of cedar poles is comparatively uniform. It is often economical to use sawn redwood poles where there is an excessive demand for any one size, because of the facility with which poles of a given size may be provided, and at the same time not react unfavorably on the price, as it would in the case of a heavy demand for a particular size of corresponding cedar poles. This economy was recently practised in the construction of a line from Banning, Cal., to Yuma, Ariz., where approximately 7,000 redwood poles of the same dimensions were used—20 ft. (6.1 m.) long, 5 in. (12.7 cm.) tops, 9 in. (22.8 cm.) butts.

At present the supply of cedar poles is obtained principally from that part of Washington adjoining Puget Sound, because of the cheap water transportation to other points on the Pacific coast. There is still much available pole timber in the interior of Washington, Oregon and Idaho, which has not yet been drawn on to any great extent.

In many portions of the western timber country, there are large quantitites of fire killed timber conveniently situated for water transportation. This timber has heretofore been considered worthless either for structural purposes or for poles, but from recent investigation it is thought to be as valuable for poles as live timber. It will probably come into extensive use in the near future, as it comprises about 15 per cent of the available pole supply. These poles are particularly adapted to treating because of their thorough seasoning.

Split cedar poles have a limited use in localities where small round cedar poles are not available. These poles are obtained by splitting larger trees where it is not economical to have them sawn. It is generally conceded that they are more resistant to decay than sawn poles, because the cells are not opened as in sawing. However, they are very unsightly and are not used where the appearance of the lead is essential.

Destructive Influences. Of all factors which tend to influence the selection of a timber for pole work, the rate of butt rot is undoubtedly the most important. Even when exposed to the same conditions, the life of untreated poles of equal size may vary from two to twenty years or more, depending on the variety. However, if a pole could be obtained large enough, it could be designed for any reasonable definite life if the rate of rot could be determined.

The generally accepted theory of rot is that it is caused by a low form of life termed fungus which excretes substances which either dissolve or cause a gradual deterioration of the fibre of the wood. Many conditions enter to affect the rate of rot of a given pole, *i. e.*, the moisture, temperature, air supply, the food value to the fungi of the wood in question, nature of the soil, amount of drainage, and perhaps the stresses to which the pole is subject. The latter at first may not seem important, yet it has been noticed that corner poles, and poles subject to repeated shock, rot at a considerably more rapid rate than others, possibly due to fibre fatigue and the consequent lessening of the timber resistance to decay. The four essentials to rot, or the life of fungi, are air supply, moisture, warmth and food. The absence of any one of these will prevent decay.

The principle underlying nearly all preservative treatments is the removal of any one or more of these essentials. The difficulty of regulating the first three, *i. e.*, air supply, moisture and temperature, may readily be appreciated, but the removal of the food value may be accomplished by impregnating the timber with some toxic substance, such as creosote, zinc-chloride or copper sulphate. The latter two salts leach out quite rapidly, but the creosote will remain in the wood for quite an extended period, even when submerged in water, and is effective in preventing fungi from entering the wood.

The other agencies acting at the base or ground line of the pole, such as erosion, fibre fatigue, or chemical decomposition in the direct sense, are of little importance in the absence of fungi.

However, butt rot is by no means the only destructive influence encountered. In the San Joaquin valley, near Middle river, a section of line a number of miles in length has several times been burned by slow peat fires. If this trouble becomes more serious, it may be necessary to imbed the poles in a footing of loose gravel of sufficient thickness to prevent the heat from injuring the pole. For a short distance over the Yuma-Los Angeles line, after entering the desert country, the poles are subject to a sand-blasting action due to the sand carried by the strong winds. Fig. 3 illustrates the destructive effect of these storms on survey stakes which were in the ground for a period of only four or five months. Many remedies have been suggested, such as non-drying paint, which will collect a sand coating, metal sheathing, or some paint which would present a hard stone-like surface. For a number of years the Western Union Telegraph Company has protected its poles from this action by placing stubs on the windward side.

In addition to the conditions named, which work towards the destruction of pole lines, there are storms, fires, white ants, woodpeckers and other minor agencies.

Rate of Decay. As before stated, the life of any given pole is very uncertain. However, if a sufficient number of measurements are taken at the point where maximum decay occurs, a very close determination of the average rate of decay of any given wood may be determined for a given territory.

A very extended determination of the average rate of butt rot of Eastern white cedar has placed it at about 0.3 in. (7.6 mm.) in circumference per year as an average under all conditions.

That of Western cedar is probably approximately the same. However, steps are being taken to determine this rate accurately for the Pacific coast for redwood and Western cedar poles. The rate for redwood varies with the physical characteristics of the wood. Some portions of the butts (*i.e.*, "butt cuts") show remarkable resistance to decay, while sapling and "top cuts" often decay rapidly. The rate of decay of sawn redwood is now considered to be approximately the same as that of cedar, although this is probably too great due to the fact that sawn redwood poles contain no sapwood.

In this connection, it might be interesting to state that the point at which decay proceeds most rapidly is just below the ground line for Eastern cedar, and about four to eight in. (10.1 to 20.3 cm.) below for Western cedar.

Strength of Poles. Realizing the importance of Western cedar and the necessity for definite information regarding its physical characteristics, the Pacific Telephone and Telegraph Company undertook to obtain the modulus of rupture or the ultimate unit outer fibre stress of poles used in the construction of its lines.

It is a well established fact that in order to obtain the true modulus of rupture of a given timber, actual structural timber must be tested. Since this is the first test performed in the West on poles in a manner closely approximating the conditions existing in the line, it may be of interest to describe somewhat in detail the methods of conducting the test and the conclusions drawn.

POLE TESTS

Specimens. Eighty poles were carefully selected as representative of the forest run used for pole work. They were of three classes—Western cedar from Idaho, Western cedar from Washington and Port Orford cedar from the western slopes of Oregon. From each of these three classes specimens were selected as follows:

Length ft.	m.	6-in. (15.2 cm.) top	7-in. (17.7 cm.) top	8-in. (20.3 cm.) top	9-in. (22.8 c.m) top
25	7.6	3 or more	3 or more	3 or more	
30	9.1	3 or more	3 or more	3 or more	
35	10.6		3 or more	3 or more	3 or more

The Western cedar at the time of the test had been cut from one to eight years from live growing timber. The poles were about equally divided between summer and winter cut. The

Port Orford cedar had been summer-cut 23 months before testing from fire-killed standing timber. As would be expected from the length of time they had been cut, the poles were well air-seasoned. No consistent method was followed in seasoning, and consequently some poles contained very large weather checks, while others which received less rigorous treatment were in good condition.

Apparatus. Figs. 4 and 5 give a clear idea of the apparatus

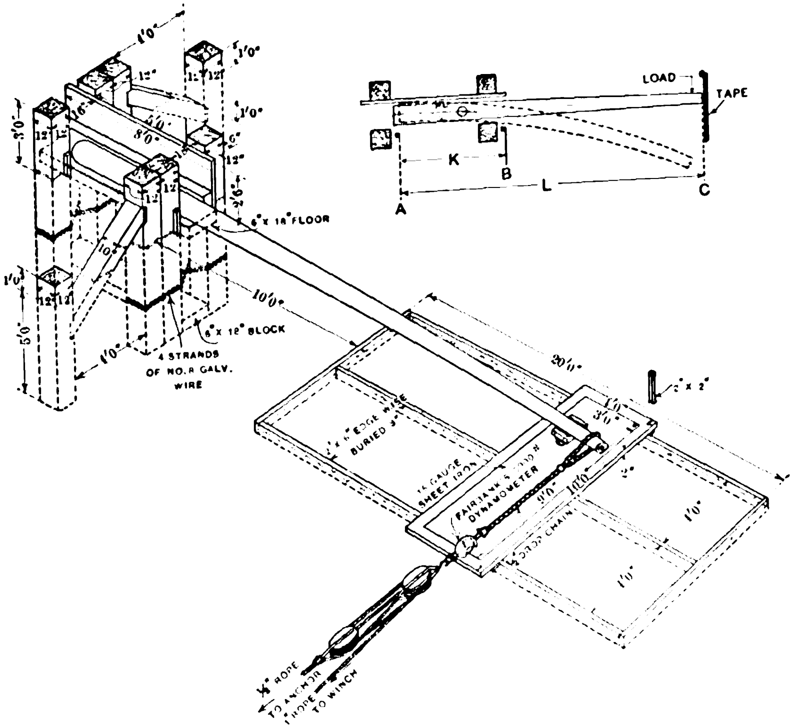

Fig. 5.—Isometric Drawing of Testing Apparatus

and its dimensions. The uprights were made of 12 in. by 12 in. (30.5 by 30.5 cm.) Douglas fir, thus making the apparatus very rigid. The conditions of actual service were duplicated as nearly as possible, the pole being inserted between the uprights six ft. (1.8 m.) from the butt, or at about the average ground line. The main part of the pole extended forward free from all obstructions to a metal covered platform where the end rested upon a metal carriage, which in turn traveled on the metal platform. The carriage was provided with easily running truck castors to facilitate its travel in a circular path. A constant pull of ten pounds (4.5 kg.) was necessary to overcome the friction of the carriage, final readings being corrected by this amount.

All deflection readings for the crushing of the pole at the butt and ground line, the movement of the machine and the top deflections were taken from stakes driven into the ground, and entirely independent of the machine. The top deflections were corrected for the crushing at the ground line and butt and the movement of machine by an amount equal to·

$$D_b \frac{(2L - K)}{K}$$

Where L = length of pole

K = distance between supports

D_b = movement of pole at B (See B, Fig. 5) due to crushing of wood and movement of support.

This formula applies only to the case where the movement at A and B is the same, which was found to be true in practically all cases.

The traction dynamometer was calibrated, the true reading being plotted against the observed reading. The winch and tackel gave a mechanical advantage of 150.

Method of Conducting Test. The test specimen was first carefully examined and noted for defects, such as injuries to sapwood from rough handling, grubs, worms, ants, bark trimmer's axes, weather checks, (star or ring), butt or top rot, large knots, an excess of sapwood or very irregular sections. The weight was obtained by the use of a pair of spring scales suspended from a tripod. The dimensions of the pole obtained were top circumference butt circumference, circumference six ft. (1.8 m.) from the butt, circumference of the center, in inches, and the length in feet.

The specimen was then lifted into the machine, six feet (1.8 m.) of the butt blocked tightly against the uprights, and an initial tension put into the rigging to clear all obstruction. The length of the lever arm was then obtained.

The pole was deflected at the constant rate of one ft. (30.5 cm.) per minute until failure took place, deflection readings being taken at the top, ground line and butt for each load increment of 100 lb. (45.3 kg.) The top readings were taken from a nail driven into the center of the pole to avoid errors due to unequal fibre strain or rolling. After failure, the distances from the

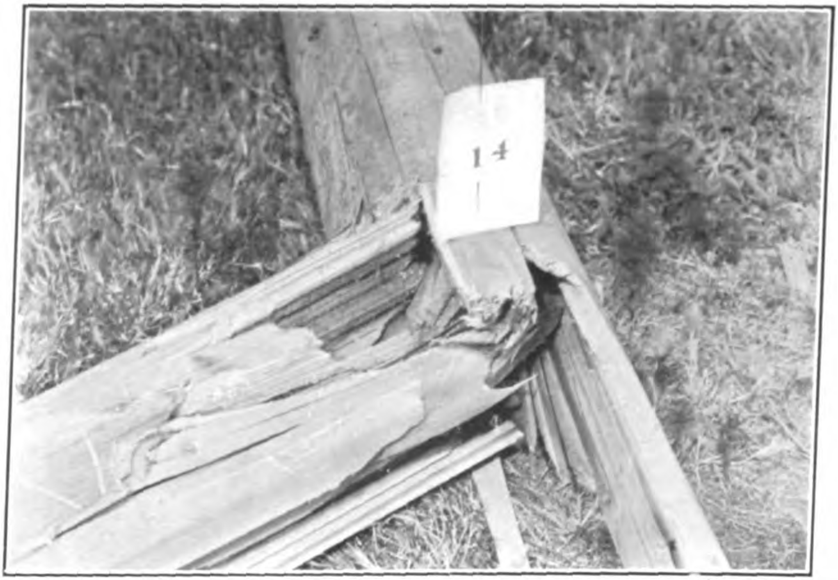

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FIG. 6.—TYPICAL BREAK OF WESTERN CEDAR FROM IDAHO

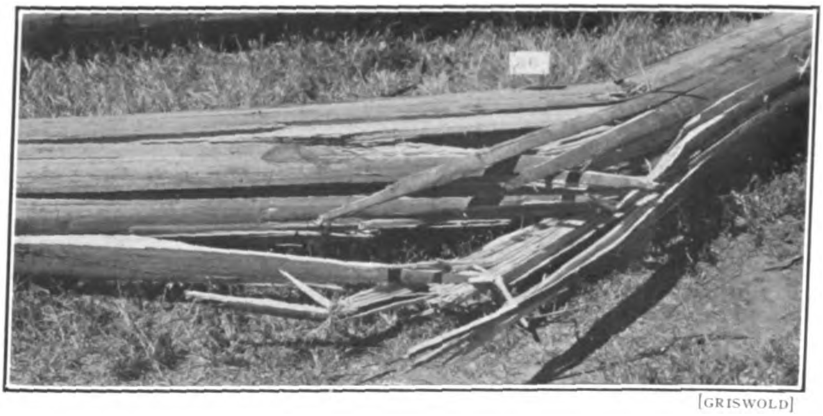

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FIG. 7.—TYPICAL BREAK OF PORT ORFORD CEDAR

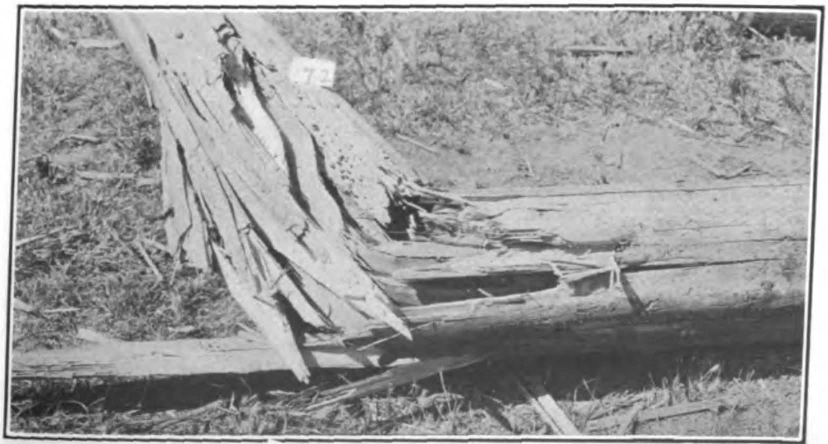

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FIG. 8.—TYPICAL BREAK OF WESTERN CEDAR FROM WASHINGTON

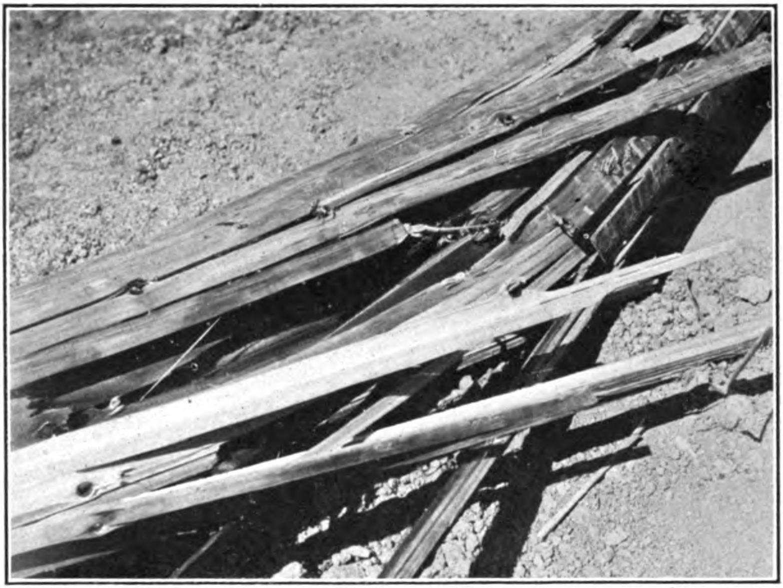

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FIG. 9.—EFFECT OF AXE-CUTS IN LOCATING POINT OF FRACTURE

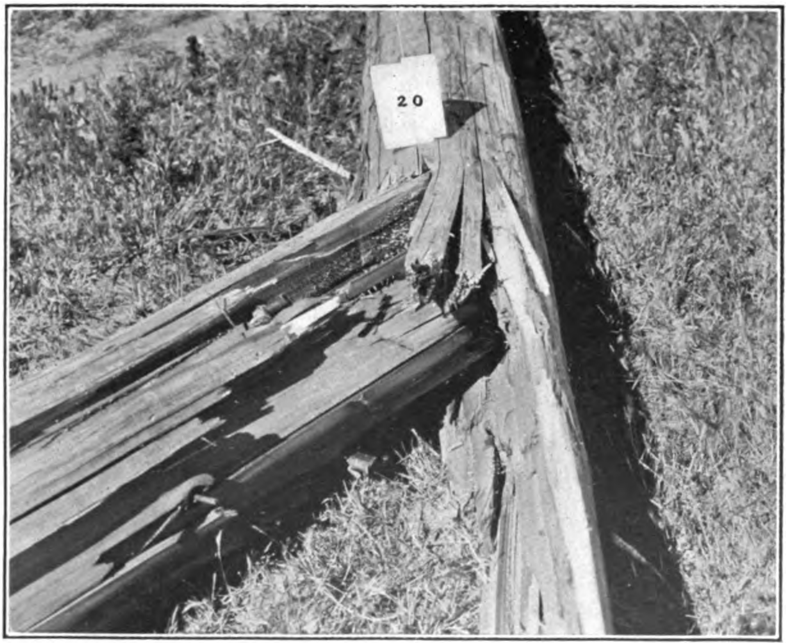

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FIG. 10.—SHOWING EFFECT OF EXCESS OF SAPWOOD, DUE TO RAPID GROWTH

point of fracture to the top and ground line were measured. The circumference at the point of fracture was calculated from the dimensions previously obtained. After examining the nature of the fracture and photographing, a one-in. (25.4 mm.) section to be used as a moisture sample was obtained as near the point of failure as possible. These sections were also used to obtain the rings per inch and percentage of sapwood. The samples were weighted immediately after cutting and again after being oven-dried to a constant weight, the percentage of moisture being then calculated in terms of the dry weight. Figs 6 to 10 show typical fractures for the woods tested and the effects of the various defects encountered.

Calculations of Tests. The pole was treated as a tapered cantilever beam and the calculations for the modulus of rupture made by means of the fundamental formula, $S = \frac{MC}{I}$ assuming that this law holds to the point of rupture. In obtaining the volumes and weights per cubic foot, the pole was treated as a truncated cone.

Following are the data obtained, and curves, Fig. 11, show the comparative strengths of the timbers tested:

POLES 1-27 INCL.

WESTERN CEDAR (*THUJA PLICATA*) FROM IDAHO

Modulus of rupture lb. per sq. in.	Moisture content per cent	Sapwood per cent of total area	Rings per inch	Weight per cu. ft. lb.	Load at failure lb.
5,270	10.	26.	20.	22.7	2,214 (1,004.2 kg.)

POLES 28-51 INCL.

LAWSON CYPRESS OR PORT ORFORD CEDAR (*CHAMAECYPARIS LAWSONIANA*)

FROM WESTERN SLOPES OF OREGON

7,220	12.		16.	26.7	3,040. (1,378.9 kg.)

POLES 55-81 INCL.

WESTERN CEDAR (*THUJA PLICATA*) FROM OREGON AND WASHINGTON

5,350	15.	34.	12.	21.9	1,928 (874.5 kg.)

NOTE.—The per cent of sapwood was not calculated on Port Orford cedar because of the difficulty in differentiating between the heart and sapwood on many of the samples.

Conclusions from Tests. Weather checks are an important factor in the weakening of Port Orford cedar, and as in the case of red cedar, the more rapid the growth the weaker the pole.

The analysis of the cause of weakness of any pole was made difficult by the insufficient data on the history of the particular poles tested. The principal causes of weakness of Western red cedar, in order of their importance, seemed to be:

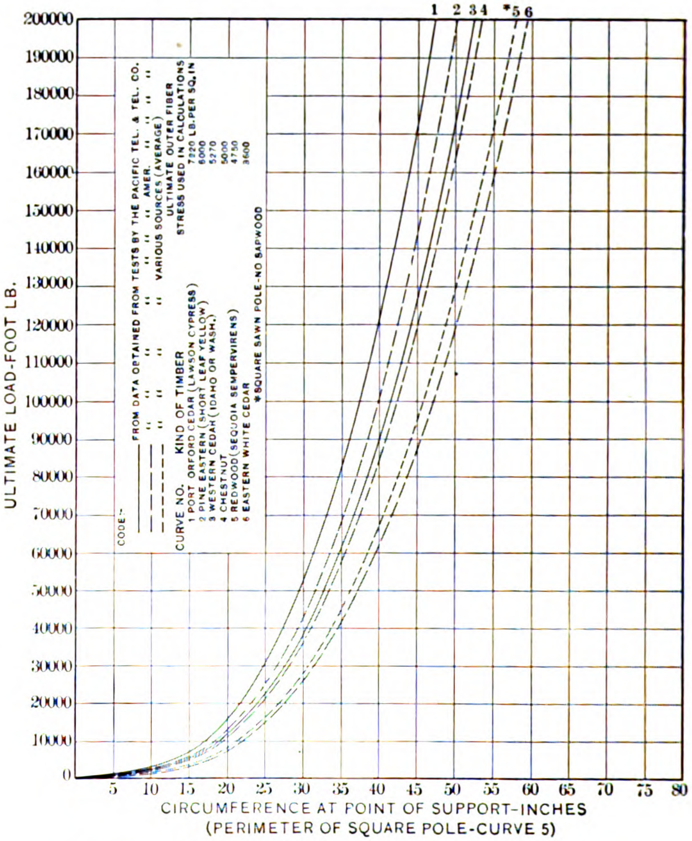

FIG. 11.—COMPARATIVE STRENGTH OF POLE TIMBERS

1. Injury to sapwood
   - *A* Teredo pitting
   - *B* Bark trimmer's axe cuts. (See Fig. 9)
   - *C* Bruising
2. Rapid growth
3. Excessive sapwood (See Fig. 10)
4. Weather checks
5. Knots.

Injury to sapwood, although of very great importance in reducing the initial strength of the pole, has probably no bearing on the effective life. No center rot being encountered, conclusions were not formed as to its bearing on the strength of the pole.

Due to the low moisture content of the poles tested, no conclusions could be drawn as to the effect of moisture on the strength of poles. However, since poles used in line construction are generally cut several months before being set, they are usually moderately well seasoned and under such conditions the moisture content cannot be considered of any great importance.

The results of the tests of Port Orford cedar are far more consistent than those of Western cedar, due probably to the timber being more uniform in age and quality.

The data show definitely that the Western poles are not of an economical taper and that the ground line is the critical point.

In obtaining the data given above, only those poles which contained defects as listed in the specification adopted by the Pacific Telephone and Telegraph Company were discarded.

CLASSIFICATION AND SPECIFICATIONS

The strength and rate of rot of poles are of fundamental importance in determining their life under a given load. The ultimate load to which the pole is subject may be determined with a reasonable degree of accuracy. The life assigned is dependent upon the increase of load necessitated by the development of the surrounding country, probable changes in equipment and new laws or ordinances affecting the construction and the economical life as determined by a cost study. With the life assigned and the load known, it is only necessary in order to obtain the original circumference at the time of setting to add sufficient wood to allow for the rot at the ground line during the life of the pole.

In drafting specifications for poles, it is desirable to utilize as great a portion of the forest run of poles as possible, in order that there shall be no reaction on the price due to the excessive demand for any particular size.

The following specifications based on these factors for Western cedar poles, with the classes assigned according to the importance and size of the lead, will further illustrate the application of this principle.

Length of poles		*A* (Minimum top circumference 28 in. (71.1 cm.) Circumference 6 ft. from butt		*B* (Minimum top circumference 25 in. (63.5 cm.) Circumference 6 ft. from butt		*C* (Minimum top circumference 22 in. (55.8 cm.) Circumference 6 ft. from butt		*D* (Minimum top circumference 18½ in. 47 cm.) Circumference 6 ft. from butt		*E* (Minimum top circumference 15 in. (38.1 cm.)	*F* (Minimum top circumference 12 in. (30.5 cm.)
ft	meters	in.	cm.	in.	cm.	in.	cm.	in.	cm.		
20	6.1	30	76.2	28	71.1	26	66.0	24	60.9	No butt requirement	No butt requirement
22	6.7	32	81.3	30	76.2	27	68.6	25	63.5		
25	7.6	34	86.3	31	78.7	28	71.1	26	66.0		
30	9.1	37	94.0	34	86.3	30	76.2	28	71.1		
35	10.6	40	101.6	36	91.4	32	81.3	30	76.2		
40	12.2	43	109.2	38	96.5	34	86.3	32	81.3		
45	13.7	45	114.3	40	101.6	36	91.4	34	86.3		
50	15.2	47	119.3	42	106.7	38	96.5	36	91.4		
55	16.7	49	124.4	44	111.7	40	101.6	38	96.5		
60	18.3	52	132.1	46	116.8	41	104.1	39	99.0		
65	19.8	54	137.1	48	121.9	43	109.2				

The foregoing specifications do not require seasoned poles; however, it is preferable to use seasoned poles because of the lessened weight and subsequent lessening of the cost of freight charges and handling. Well seasoned cedar poles may lose from 20 to 35 per cent of the original weight, depending on the season in which they are cut. Autumn and winter cut poles will usually lose the greatest percentage of weight. A material increase of strength follows thorough seasoning. The weights of green poles vary from 34 to 39 lb. (15.4 to 17.7 kg.) per cubic foot (0.0283 cu. m.), while that of seasoned poles may be from 20 to 26 lb. (9.07 to 11.8 kg.) per cubic foot.

The top size specifications in general use at present are entirely irrational inasmuch as the top size of a round pole is no indication of its desirability or life under a given condition. The taper may vary considerably on a given top size pole, depending upon the environment in which it was grown, the judgment of the cutter and many other uncertain factors.

The average circumference taper of Western cedar is slightly less than three in. (76.2 mm.) per 8 ft. (2.44 m.) of length, while that of Port Orford cedar is three in. in circumference per 10 ft. (3.05 m.) of length.

A pole of economical taper, disregarding decay, would be one that theoretically would not break at any one point, more readily than at any other point, *i. e.*, the unit stress of the most strained fibre would be a constant for any section of the pole. Since the strength of a pole increases as the cube of the diameter, an economical taper would require a pole of a taper that is probably never reached in practise. For instance, a pole seven in. (17.8 cm.) in diameter at the point of load would require about a 22-in. (55.9 cm.) ground line diameter if the load were applied 30 ft. (9.1 m.) from the ground line. In addition, butt rot is continually reducing the effective taper. Sawn poles have the advantage that any desired taper may be obtained at will, of course, within practical limits.

Pole Spacing.—The spacing of poles varies greatly, and depends principally on the nature of the conductors, degree of exposure to the elements, and the factor of safety desirable.

The above specifications are based on about a 15-year life with a spacing of 130 ft. (39.6 m.) for 60 wires or less, and 120 ft. (36.5 m.) for 61 to 80 wires and on the assumption that the line will be subjected to a wind of 50 miles per hour and a sleet load of ¼ of an inch (6.3 mm.) in thickness and that the conductors are all of the average size used in telephone line construction. If it is desired to increase the life of a line, the span is shortened, thus reducing the load per pole and obviating the necessity of increasing the size of the pole. Because of the increasing cost and relative importance of lines which exceed a capacity of 70 wires, the spacing is reduced from 120 ft. (36.5 m.) for 70 and 80 wires to 100 ft. (30.5 m.) for 70 wires, and 90 ft. (27.4 m.) for 80 wires, where severe weather conditions exist. This has been done to increase the life and reduce the liability to accidents, and thus bring the pole line in cost equilibrium with the remainder of the outside plant.

Where it is desirable to take advantage of local favorable conditions, this may be accomplished either by increasing the span or decreasing the size of the pole. The latter method would involve very little saving outside of the decreased cost of handling poles of lighter weight and the difference in cost of the smaller poles, except where a heavy demand for poles of a larger size would react unfavorably upon the price. The first method, however, presents several advantages, such as the saving of the first cost and erection cost of several poles per mile with the necessary fixtures, and may be adapted to make all portions of a line consistent with the varying degrees of exposure to the elements.

Because of the wide range of weather conditions existing in the Pacific Coast territory two spacings have been designed, one applicable to localities where severe weather conditions exist and another to regions of mild weather conditions. The considerable saving effected may readily be appreciated by the comparison of the two spacings.

	Ultimate Capacity		
	80 wires	70 wires	60 wires
Severe conditions	90 ft.-27.4 m.	100 ft.-30.5 m.	130 ft.-39.6 m.
Mild conditions	130 ft.-39.6 m.	155 ft.-47.2 m.	200 ft.-60.9 m.

It must also be understood, that the spacing for mild conditions is less than would be theoretically possible because of other limiting factors, such as greater relative importance of the larger lines, danger of swinging contact of wires and an endeavor to maintain the line in cost equilibrium with the remainder of the outside plant.

Replacement of Poles. Realizing the importance of uninterrupted service, and the variation of conditions affecting butt rot, a replacement inspection for pole lines has been provided. Although a line is generally designed for a 15-year life, the first inspection takes place eight years after erection and others every three years thereafter. It is the practice to allow the pole to reach approximately a safety factor of one before replacing. However, if the line is considered of unusual importance, or unfavorable conditions exist, a safety factor slightly greater determines the point of replacement. In order to introduce these factors and varying degrees of exposure to which a given line may be subject, replacement tables should be compiled, giving the minimum allowable circumference of sound wood at the ground line. The application of the replacement size necessarily is regulated entirely by the actual load upon the pole and not by the ultimate capacity.

LOADS

Except in lines carrying very heavy circuits, the column load may be disregarded and the lateral wind need only be considered in calculating the pole stresses due to wind loads.

The severity of conditions provided for may not necessarily be the most extreme that long experience has proved possible, as a cost study may prove definitely, for instance, that it may be more economical to assume the risk that the line may be wrecked before its economical life is reached rather than to build it sufficiently strong to withstand the maximum stresses possible over that period of time. In calculating wind loads added surface exposed to the wind by the accumulation of sleet is one of the most important items to be considered. In order to avoid unnecessary complications, the column load is neglected, the pole and steel-covered conductors considered as circular in section, and the wind as blowing horizontally and at right angles to the lead. Under unusual conditions, the sleet may accumulate to a thickness of two in. (50.8 mm.). However, 0.25 in. (6.3 mm.) of sleet for small conductors and 0.5 in. (12.7 mm.) for large conductors are thought to be conservative amounts for which to provide. Wind velocities may exceed 100 miles (161 km.) per hour. However, a wind of 50 or 60 miles (80.4 or 96.5 km.) per hour is generally the maximum considered. Two types of weather conditions are considered—sever and mild,—the former governing the territory of probable sleet storms and wind velocities of 50 miles (80.4 km.) per hour or more, and the latter the territory where neither sleet nor winds exceeding 60 miles (96.5 km.) per hour occur. Fig. 12 is a copy of a map which was designed to show, in a general way, the blanket areas in which these conditions are encountered.

SAG OF WIRES

The calculation for the sag of wires is based on the equation of the catenary. The fact, however, that the conductor is an elastic material under tension must not be lost sight of when obtaining the result of a change in load. The component forces acting on a wire are the wind horizontally, the weight of the wire and the weight of ice or sleet vertically; the resultant of these represents the total force. The expansion and contraction due to temperature changes must also be considered. The general practice in calculating sag is to start with the most severe condition thought economical to assume, *i. e.*, maximum sleet, minimum temperature and maximum wind velocity and to assign the safety factor; generally 2. The sleet and wind loads are then considered as being released. This release of load reduces the tension in the conductor, which in turn contracts and lessens the sag. The lessening of sag again increases the tension and between the two conditions a point of equilibrium is reached. The conductor being now at the minimum temperature, the temperature is assumed to rise, causing the conductor to expand.

Here again the tension is released, and the conductor, due to its elasticity, contracts until a second point of equilibrium is reached for the temperature rise assumed. Thus the sag may be determined for any temperature.

With copper or other conductors with a large coefficient of expansion, it is well to obtain the sag at the various temperatures at which it is probable the wires will be strung. With other conductors, it is well to give them the benefit of the doubt by assuming that the maximum temperature exists when stringing.

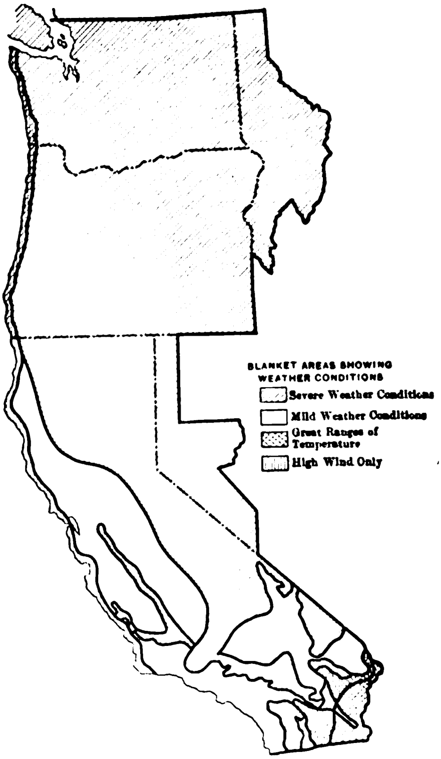
BLANKET AREAS SHOWING WEATHER CONDITIONS
Severe Weather Conditions
Mild Weather Conditions
Great Ranges of Temperature
High Wind Only

FIG. 12.—MAP SHOWING GENERAL WEATHER CONDITIONS ON THE PACIFIC COAST

CROSSARMS AND PINS

The majority of the crossarms used in this territory are obtained in the Oregon and Washington territory and are sawn from Douglas fir. This timber is cheap, strong and durable when used for this purpose and has been very satisfactory both in the untreated and treated form.

Locust pins are generally used due to their great strength and resistance to decay. However, the supply of this wood is limited, and experiments are being made on other kinds of wood by the Government in conjunction with the Pacific Telephone and Telegraph Company. These experiments have not been carried on a sufficient length of time to determine the relative merits of the woods under observation.

GUYING

The problem of guying present no features peculiar to this territory. The pole lines are designed to stand unassisted under the assumed conditions, and guys are placed either to afford an additional factor of safety or to cope with the local conditions which cannot be foreseen in the broad problem of design.

In general, guys are placed to accomplish one or more of the following purposes:

1. Supporting unbalanced stresses of conductors, due to dead-ending or change of direction.
2. Balancing loads caused by the attachment of foreign fixtures.
3. Preventing a local break from running each way along the line.

Cases 1 and 2 cover the placing of guys to meet unforeseen conditions, and Case 3 affords an additional factor of safety.

STANDARDIZATION

During the infancy of the telephone development in the Western States, the first cost was considered the main factor in the design of pole line construction, and the importance of reduction of maintenance cost and the continuity of service was not realized. Now, however, due to the realization of the importance of these factors, a great many of the early construction methods are either obsolete or obsolescent.

Many refinements have been introduced into pole line design which have had an important bearing on the economy of construction and maintenance. Naturally, the larger pole-using companies have been the first to put these practises into effect, but it is to be hoped that all companies will follow their lead, and that a very desirable standardization of materials and methods will result.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16-20, 1912.

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(Subject to final revision for the Transactions.)

PRACTICAL JOINT POLE CONSTRUCTION

BY J. E. MACDONALD

The object of this paper is to set forth the Los Angeles method of joint pole construction, which five years of practise has proven to be a workable scheme.

Independent operation, accompanied by very rapid development and expansion, had permitted pole conditions to become extremely objectionable to the public as well as to the corporations responsible for them. This reached a critical stage in 1906, when agitation for underground subways for all public utilities marked the beginning of the present cooperative policy. Distribution by the underground method, except in the business district, is impracticable, for the reason that the populated districts demanding service are scattered over a very wide range of territory, there being entire absence of congestion anywhere.

The problem of joint pole construction was taken up for solution by the principal companies and the result was a general agreement covering the different phases of the work as seemed best fitted for local conditions. These conditions were favorable for the consummation of the project. The old construction stood out boldly as an object lesson in dangerous and unsightly congestion. The undeveloped but rapidly growing districts offered a field for trying the proposition under favorable conditions without any complications. There were some problems in the older districts which were not so readily solved, chief of these being difficulty of eliminating the capital charges against the existing overhead system of each operating company. It is evident that if any poles are removed before the expiration of their natural life, or if wires are transferred which are providing adequate service, then a certain portion of the original investment must be absorbed in some manner in reconstructing on joint poles. This factor was given proper consideration in the preliminary investigations made in arriving at a satisfactory working agreement. A policy was adopted making the participation in such joint construction entirely optional with each company. However, when any poles are set, it is always with a view to providing space for all parties operating in such location. Even with this liberal policy, there have been but few cases where all companies have not found it to their advantage and profit to immediately join in such construction. Notwithstanding this condition, there has been no unequal division of the financial responsibilities, neither has there been any reason to suspect that the joint work has helped the financing of one project at the expense of another.

The working agreement, which was executed by nine companies operating in common territory, assigned the executive powers to a committee, acting without compensation. This committee is comprised of one representative from each member company, all representatives having similar authority regardless of the pole plant owned by the company represented. A secretary, appointed by the committee, is actively in charge of the details of the combination work. An officer is maintained independently of the affiliated companies, the expense being prorated uniformly against these member companies. The committee meets monthly for the discussion of combination work, and the consideration of mutual problems. The secretary is advised of all contemplated construction and reconstruction, and plans are made accordingly to provide for the service of all companies operating in the section, where proposed construction or reconstruction is to be undertaken.

The agreement makes certain fundamental stipulations; it defines the general purpose and intention of the agreement; it places certain necessary restrictions on joint work, defining the limits of good practice; it specifies the method of operating under the agreement; the term of agreement and responsibility of each company is predetermined as far as practicable; it limits the manner of occupying and space to be occupied by each party; it fixes valuations and charges, and prescribes regulations governing special expenses and maintenance.

In addition to the foregoing fundamentals, certain general regulations, which should not be considered as arbitrary rulings, have been adopted.

1. *Combined Use of Existing Poles.* In the combination use of existing poles, the combining parties use the highest or most satisfactory poles in the location where it is desired to make combination. The owner of same is permitted to bill the combining parties for a proportional interest at the rate which has been fixed for the valuation of such poles.

2. *Reconstruction by Owning Parties.* When it is desired to reconstruct a pole line in location where none of the existing poles are suitable for combination use, one of the parties operating in this location sets new poles of standard size and length sufficient for the combination use of all parties operating in this section and for any other party which may desire to obtain space on poles. The constructing or owning party then sells a proportional interest to each party making the combination at the rate which has been fixed for the valuation of such poles. Each party transfers its wires and removes its poles at its own expense.

3. *Reconstruction by New Coming Party.* When the party is occupying a favorable location on any street or highway, and a second party desires to build a pole line in the same location, if the construction of the first party is entirely satisfactory and adequate for present and future needs, that party is not obligated to assume any expense in connection with the joint occupation of the new pole line built by the second party. The latter builds pole line suitable for combination use of both parties, and grants and assigns an interest in same to the first party without charge, except that the first party transfers its wires, cross arms and fixtures at its own expense from old poles to new poles. This party removes its poles at its own expense and they remain its individual property. In special cases, however, the second party may be required to pay the entire expense incident to such transfer of wires and removal of poles, and this is determined by the committee, only those participating in the decision who are directly interested in the combination.

4. *New Pole Lines in Undeveloped Territory.* Any party desiring to construct a new pole line in location where heretofore no pole line has existed, notifies the other members, through the committee, of the proposed construction, and upon request provides space on such poles for the use of all parties who express their intention of combining in their use. The constructing party is then permitted to bill each of the combining parties for a proportional interest at the rate which has been fixed for the valuation of such poles.

5. *Renewing Poles Naturally Decayed.* All poles which have been in use as long as the committee determines that they are safe or satisfactory, or as long as the parties owning shares in same desire to use them, are replaced by new poles. The work of constructing such new pole line is undertaken by one of the parties, as determined by the committee, and this party is permitted to bill the other parties in the same manner as specified heretofore.

6. *Disposition of Joint Property Removed from Service.* Joint poles removed from service may be removed at joint expense to a place designated by the committee, where they may be sold at auction, due notice having been given to each party prior to date of sale. The proceeds of the sale are divided between the owners in proportion to the number of shares owned by each. More frequently it is desirable that such poles should be sold or disposed of before being removed, the purchaser removing same at his own expense. This may be done by mutual agreement or by an exact division of the property in proportion to the shares owned by each party.

7. *Use of Old Poles.* In the combination use of poles, those which have previously been in service elsewhere may be used, and provided that such poles are in other respects equal to new poles, are valued at the same rate as for new poles of the same height except for that portion which has been in the ground, which is considered of no value.

8. *Records.* A record map is prepared for all combinations. Poles are numbered to correspond with house numbers of adjacent property. These maps are supplements to the general agreement and furnish a complete record, specifying the number and size of poles, date when set, valuation, and such other data as may be desirable in each case. These supplements must be approved by all parties interested before any authorization for billing is permitted. A complete file of all combination work is maintained for each company by the committee.

9. *Specifications.* A specification is understood to imply only first class construction, and as a rule, deals with maximum and minimum quantities. Assuming, therefore, that each party is maintaining its lines in the highest state of efficiency, a joint specification is simply a summation of all specifications together with such modifications as are necessary to mutually protect the property of combining parties. This subject is so extensive that it cannot well be covered in a paper of this scope.

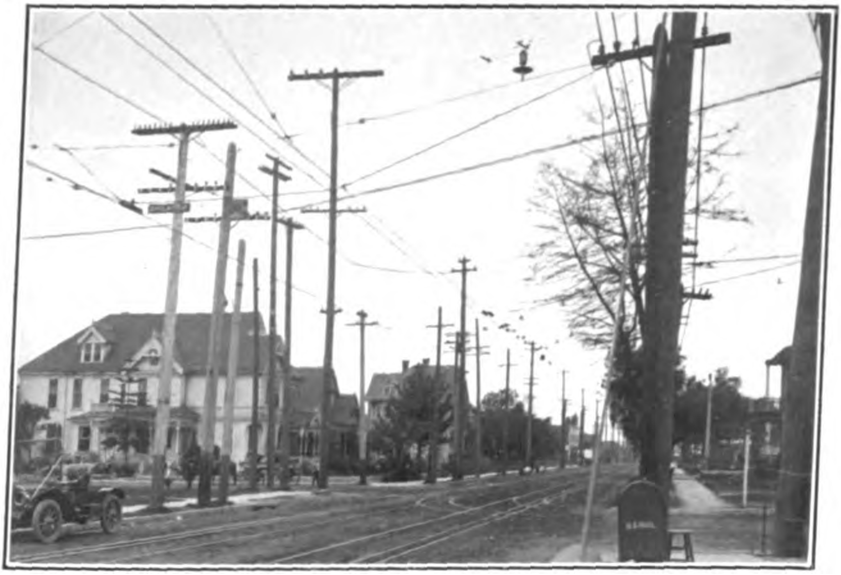


FIG. 1 [MACDONALD]

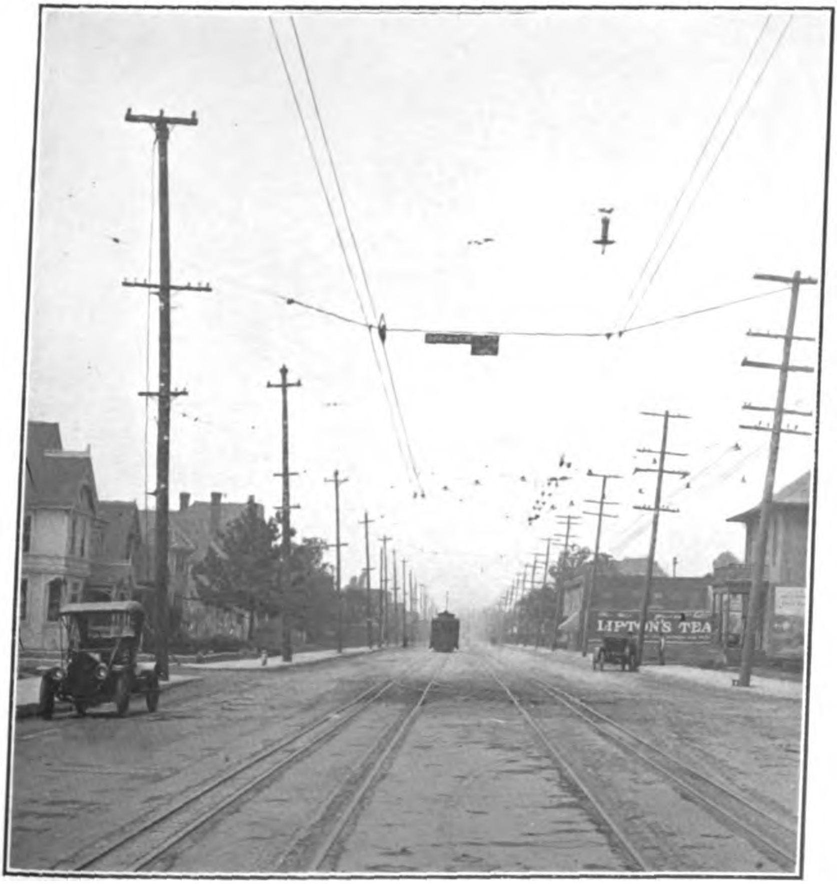


FIG. 2 [MACDONALD]

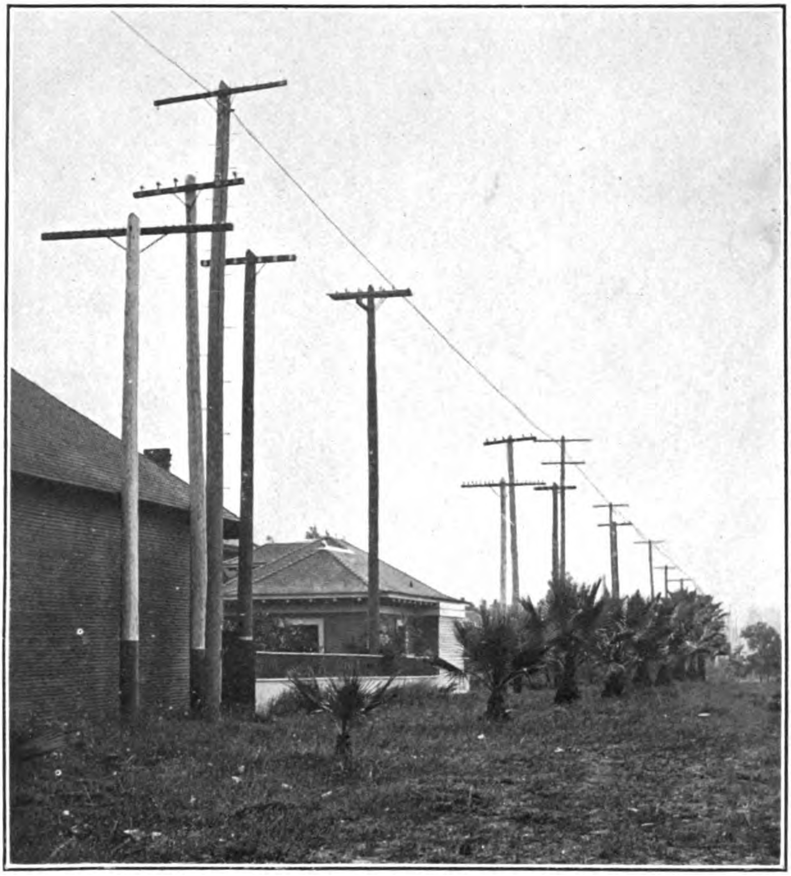


FIG. 3 [MACDONALD]

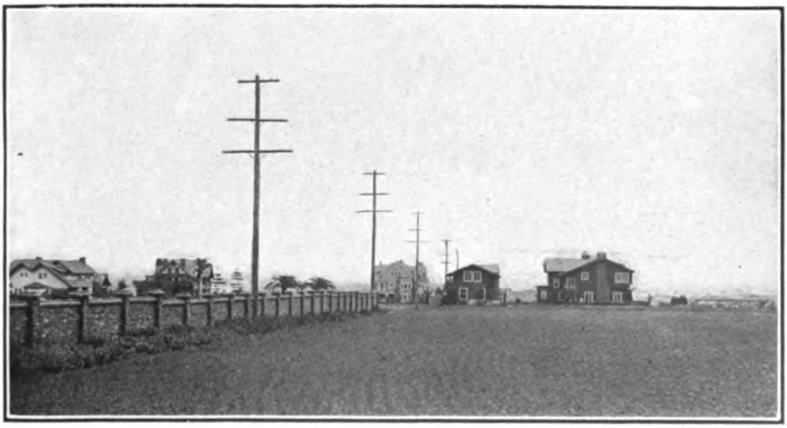


FIG. 4 [MACDONALD]

The author would refer those seeking enlightenment along this line to the specification adopted by the New York Telephone Company and the Public Service Corporation. This offers an excellent standard of construction, which is worthy of adoption. Local conditions will not demand any radical changes therefrom.

PROGRESS IN LOS ANGELES AND VICINITY

During five years of operation combinations have been recorded on 21,270 poles. By count of poles occupied by two or more parties it has been determined that the number which have been eliminated exceeds 30,000. The length of the average pole in combination use has been found to be 43.04 ft. (13.12 m.)

Figs. 1 and 2 show the condition at Sixteenth and Georgia Streets before and after reconstruction on joint poles. Sixteenth Street was widened 7.5 ft. (2.3 m.) on each side, and reconstruction was carried on by the utility companies simultaneously with the improvement of the street by the municipality.

Fig. 3 illustrates in all its crudities the results of independent operation, three lighting companies and two telephone companies maintaining individual leads on this property line. In the block shown herewith, which is 505 ft. (154 m.) long, there were ten 30 ft. (9.1 m.), nine 35 ft. (10.6 m.)and five 40 ft. (12.2 m.) poles, representing an investment in labor and material for poles alone of $285.25. The five 40 ft. (12.2 m.) poles, at an investment of $70.00, would have provided better clearances for all companies. Proper construction would demand 50 ft. (15.2 m.) poles in order to comply with a correct specification.

Fig. 4 represents a distributing lead on property line showing the advantage of joint construction where rights of way are not easily obtained. This is a standard form of construction where easements are usually provided in all new subdivisions for the installation of such construction.

Fig. 5 represents one of a number of square miles (1 sq. mile =2.59 sq. km.) of territory which has been built up during the period that the companies have been operating under the joint agreement. In 1906 this section was traversed by a transmission line and a portion of single track electric railway, on private right of way, which was operated at infrequent intervals for freight traffic only. Other improvements of any kind were lacking. It is now built up with magnificent homes, representing the very best class of residence patronage for the public service corporations. Practically all the lots front east and west, and poles have been placed on north and south property lines for distribution, while the trunk leads have been placed on main streets running east and west, upon which the electric railways have also been constructed. There are 685 combination poles shown on this plot. To accomplish the same distribution by individual construction would have required 1,903 poles, that is, provided independent construction would have been tolerated.

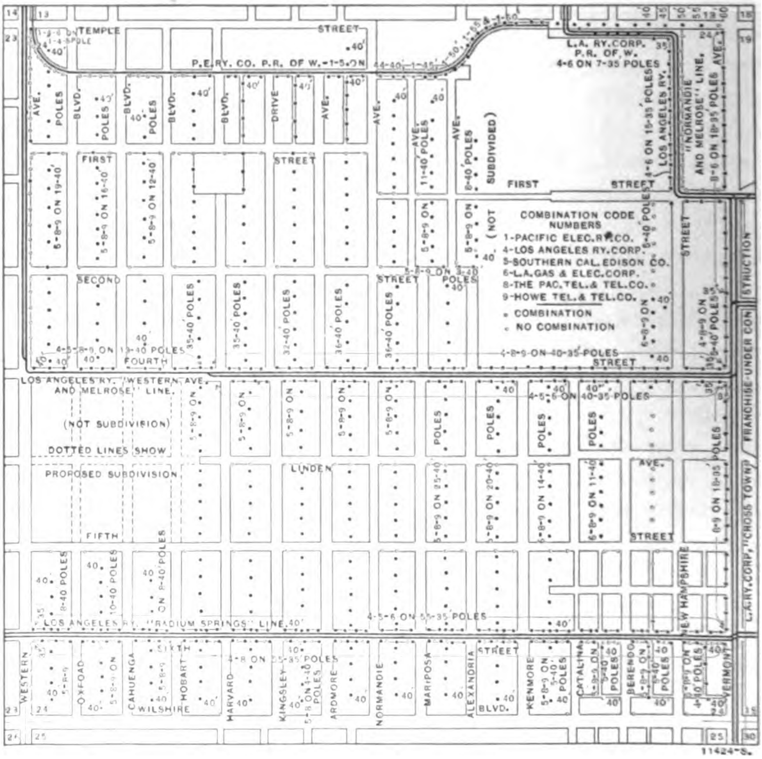


FIG. 5

In the square mile (2.59 sq.km.) there are 193 individually owned poles, which are used almost exclusively for street lighting or railway work. A few of these may ultimately become combination poles. On the south side of Sixth Street will be noted the only duplication in the entire territory. This construction was completed prior to the acceptance of the agreement by the telephone companies, and represents a superfluous pole invest-

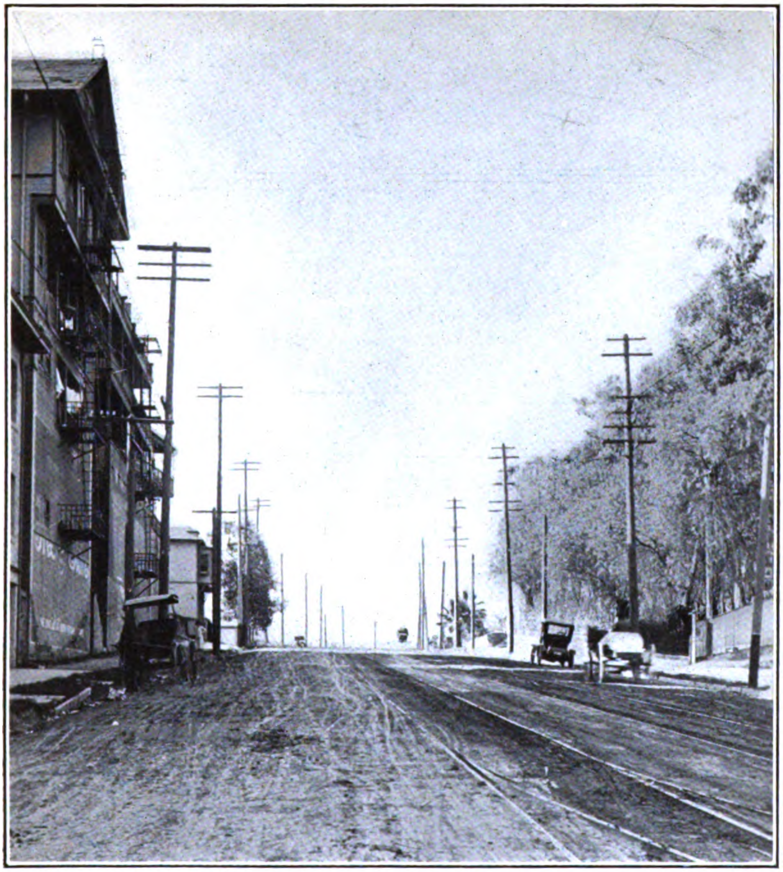


FIG. 6 [MACDONALD]

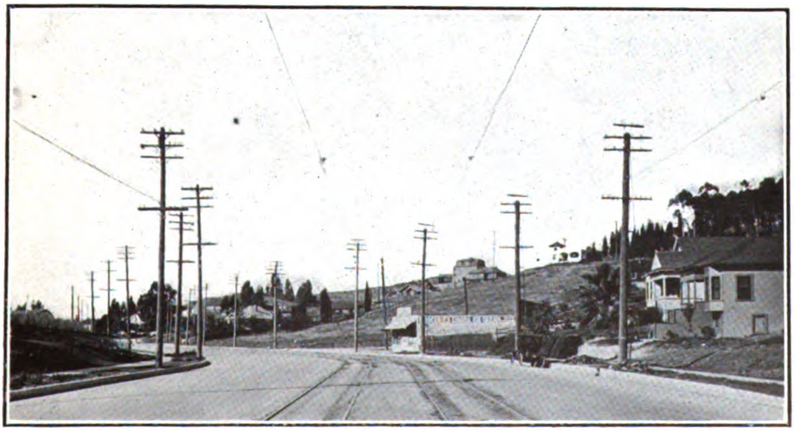


FIG. 7 [MACDONALD]

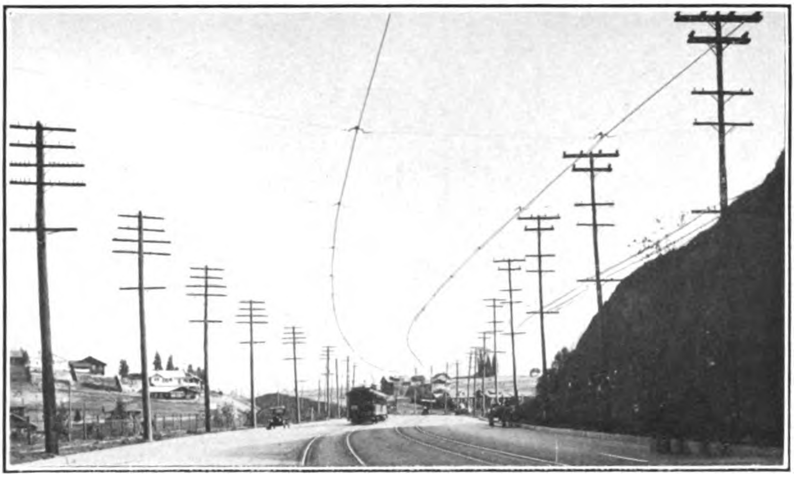


FIG. 8 [MACDONALD

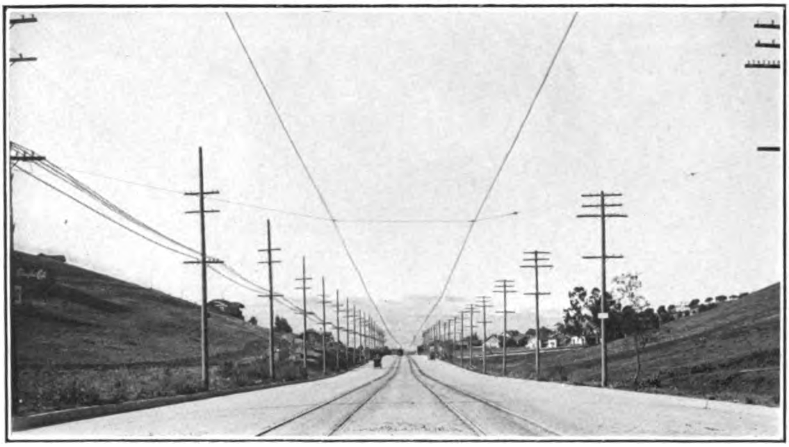


FIG. 9 [MACDONALD]

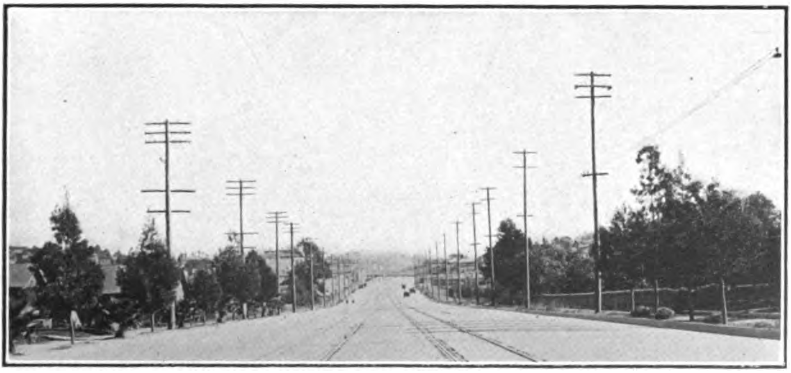


FIG. 10 [MACDONALD]

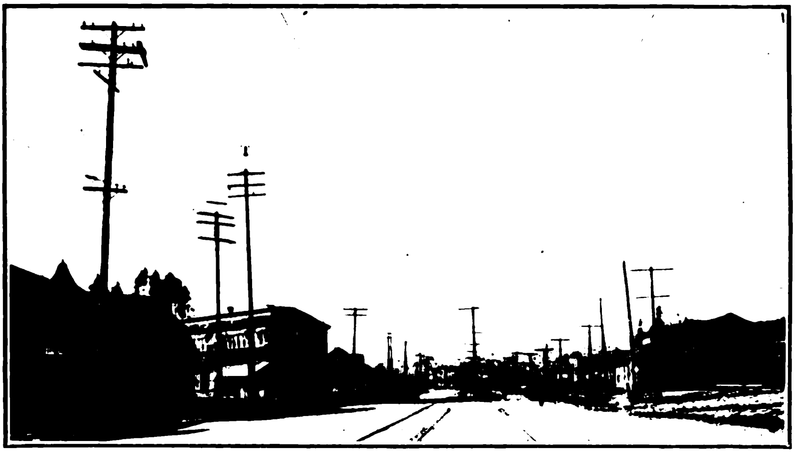


FIG. 11 [MACDONALD]

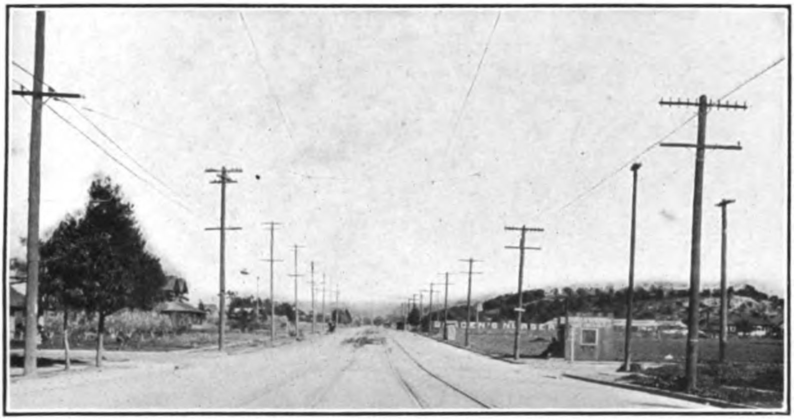


FIG. 12 [MACDONALD]

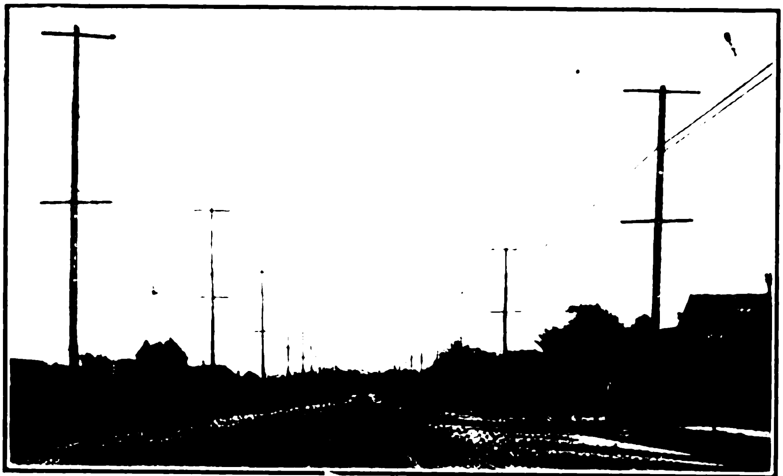


FIG. 13 [MACDONALD]

ment of approximately $614.25. It will, therefore, be noted that failure or neglect to coöperate leads to the possibility of creating objectionable construction, which may possibly be maintained during the entire life of pole line, owing to the expense of transfer.

Figs. 6 to 13 inclusive show pole conditions on Sunset and Hollywood Boulevards, one of the principal outlets to a suburban community, and represent fairly well various types of joint construction, where conduit subways would be impracticable from a financial standpoint. These form a continuous thoroughfare, extending over seven miles (11.2 km.) in length, from the extreme limit of the present conduit district. Of this there remains a distance of less than 3,000 ft. (914 m.) which is not improved from the joint construction standpoint.

Fig. 6 shows a combination which is incomplete. The city has underway the work of widening the street and reducing the grade, and joint work is to be completed by the removal of the railway company's poles. The transmission line shown on the north side of the street is the 33,000-volt Edison line built in 1897; this portion is now being operated at 15,000 volts. Poles are in fair condition and are not unsuitable for combination use.

Fig 7 represents joint construction on a curve, where it was impossible to secure permit for anchoring on private property. Poles were trussed at joint expense. There are the municipal fire alarm, two telephone companies, a telegraph company and the railway company operating on one side of the street, and two lighting companies and the railway company on the other. The telegraph company and city are not parties to general agreement, but cooperate where lines parallel.

Fig. 8 also shows joint construction on curve; poles on outside of curve have been blocked with concrete at base and at ground line, no buying being necessary. This is a combination of one telegraph company, a telephone company and the railway company on one side of the street, and two lighting companies and the railway company on the other.

Fig. 9 represents a typical straight line combination. Vacant position has been left on top of one line of poles for future installation of transmission line for the railway company. Otherwise, the combination is the same as shown in Fig. 8, except that the view is in the opposite direction.

Figs. 10 and 11 are views taken from the same point looking in opposite directions, one representing a completed combination, and the other a proposition which will be undertaken upon the improvement of the street by the municipality. The railway company owns private right of way in the center of street and has heretofore maintained center pole construction, this being removed in connection with the combination work.

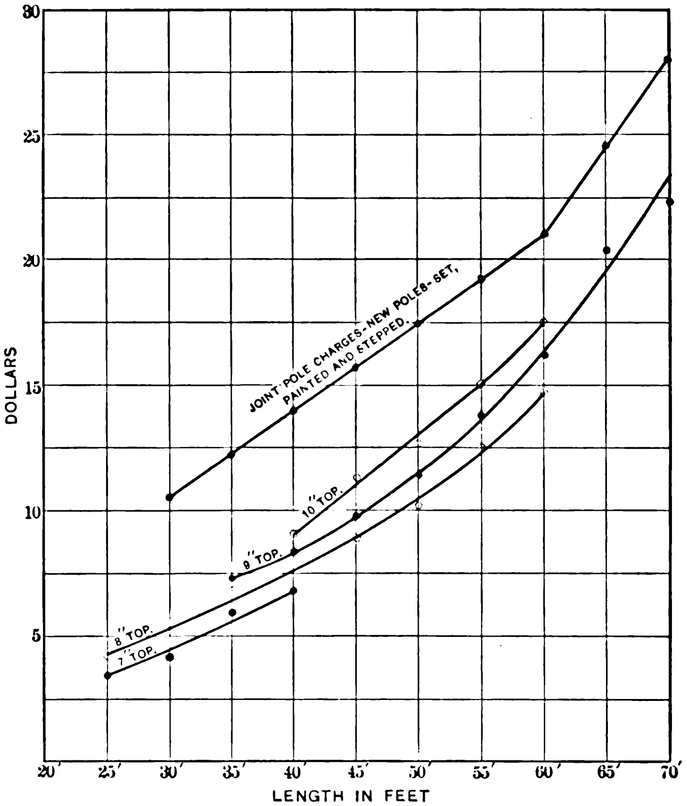
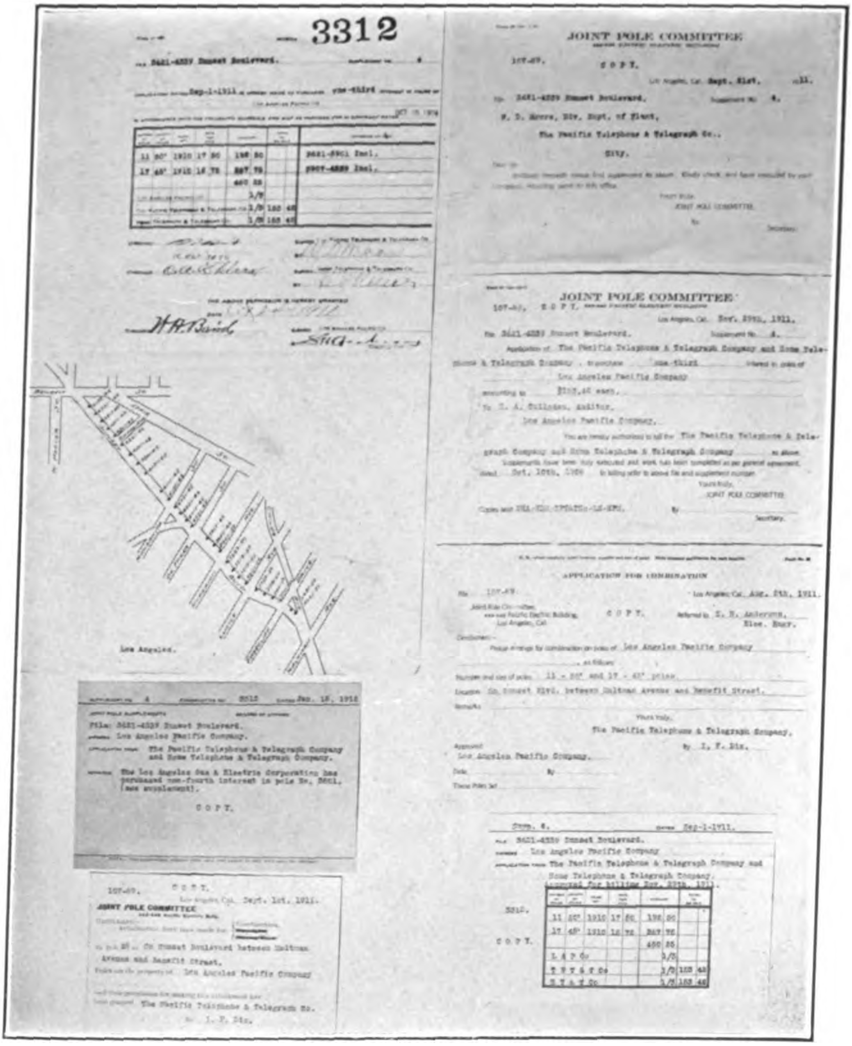


FIG. 14.—JOINT POLE CHARGES AND MARKET PRICES OF ROUND CEDAR POLES

(Los Angeles, March 1, 1912)

Figs. 12 and 13 illustrate a combination between a railway company and one telephone company, on one side of the street. On the other side is shown the conventional construction of one lighting company and of the railway company.

Fig. 14 is a series of curves showing the present market prices of poles at tidewater points, from which points distribution is



3312

3421-4339 Sunset Boulevard. 4

Sep-1-1911 one-third

11	50'	1910	17	80	195	80			3421-3901 Incl.
17	45'	1910	16	75	284	75			3907-4339 Incl.
					480	55			
Los Angeles Pacific Co.						1/3			
The Pacific Telephone & Telegraph Co.						1/3	160	18	
Home Telephone & Telegraph Co.						1/3	160	18	

W. H. Baird

Los Angeles.

4 3312 Jan. 18, 1912

File: 3421-4339 Sunset Boulevard.
Los Angeles Pacific Company.
The Pacific Telephone & Telegraph Company and Home Telephone & Telegraph Company.
The Los Angeles Gas & Electric Corporation has purchased one-fourth interest in pole No. 3601. (see supplement).

C O P Y.

107-49. C O P Y.
Los Angeles, Cal. Sept. 1st. 1911.
JOINT POLE COMMITTEE
On Sunset Boulevard between Maltman Avenue and Benefit Street.
Los Angeles Pacific Company
The Pacific Telephone & Telegraph Co.
I. F. Dix.

JOINT POLE COMMITTEE

107-49. C O P Y.

Los Angeles, Cal. Sept. 21st, 1911.

3421-4339 Sunset Boulevard. 4.

F. D. Moore, Div. Supt. of Plant,
The Pacific Telephone & Telegraph Co.,
City.

JOINT POLE COMMITTEE

Secretary.

JOINT POLE COMMITTEE

107-49, C O P Y.

Los Angeles, Cal. Nov. 29th, 1911.

3421-4339 Sunset Boulevard. 4.

The Pacific Telephone & Telegraph Company and Home Telephone & Telegraph Company one-third Los Angeles Pacific Company

$160.18 each.

To C. A. Culloden, Auditor,
Los Angeles Pacific Company.

The Pacific Telephone & Telegraph Company and Home Telephone & Telegraph Company

Oct. 10th, 1908

JOINT POLE COMMITTEE

Secretary.

APPLICATION FOR COMBINATION

107-49. Los Angeles, Cal. Aug. 7th, 1911.

C O P Y. E. B. Anderson,
Elec. Engr.

Los Angeles Pacific Company

11 - 50' and 17 - 45' poles.

On Sunset Blvd. between Maltman Avenue and Benefit Street.

The Pacific Telephone & Telegraph Company,
By I. F. Dix.

Los Angeles Pacific Company.

Supp. 4. Sep-1-1911.

3421-4339 Sunset Boulevard.
Los Angeles Pacific Company
The Pacific Telephone & Telegraph Company and Home Telephone & Telegraph Company.
Approved for billing Nov. 29th, 1911.

3312.

C O P Y.

11	50'	1910	17	80	195	80		
17	45'	1910	16	75	284	75		
					480	55		
L A P Co						1/3		
P T & T Co						1/3	160	18
H T & T Co						1/3	160	18

Fig. 15

[MACDONALD]

made locally. Supplementing this, is the curve showing the valuations according to the joint schedule for new poles set, painted and stepped. It will be noted that this gives a valuation of thirty-five cents per pole foot (0.3048 m.) for poles 30 to 60 ft. (9.1 to 18.3 m.) in length. Poles which have been set less than three years are assumed to be of the same value as new poles. Poles set from three to six years are assumed to be of the same value as new poles, but no value is given to that portion of the pole which is in the ground. Poles set over six years are assumed to depreciate at the rate of three and one-half cents per foot per annum, but no value is given to that portion of pole which is in the ground. During five years' operation under this schedule, it has been found that the valuations are approximately correct. The values given for 50 ft. (15.2 m.), 55 ft. (16.7 m.) and 60 ft. (18.3m.) poles are lower than they should be, but inasmuch as such poles are usually set by the party desiring the top position and the added length is often solely for this party's benefit, it has not been found that the charges prove inequitable.

Fig. 15 shows the practical application of certain forms which have been found useful in maintaining proper records of joint work.

During the five years under discussion no individual, save a newspaper reporter, has precipitated the query " does it pay?" It should not be necessary to furnish exact data on this point. The reduction in investment that is, the difference between the purchase and installation cost of over 50,000 poles independently and operated, as against 21,270 combination poles is subject to exact deduction. The difference in the maintenance and depreciation charges on them represents a quantity which may also be arrived at very closely. The saving in the maintenance and depreciation charges, at joint expense, of the combination poles for one year exceeds the cost of maintaining the office of the committee for the entire period of five years. In addition to this there are the intangible quantities, such as the saving which results from such a project as a matter of public policy; also the saving due to the entire absence of accidents on joint poles, on account of superior construction. Some of us might even figure on the conservation possibilities, taking the entire United States as a basis of action.

In conclusion it should be stated that whatever degree of success has attended the joint proposition in Los Angeles is due to the constant and consistent policy of cooperation which actuated the engineers of the participating companies. Not a single problem has been presented for solution which has not ultimately been passed upon by unanimous vote. The defection of even one of the nine member companies, so far as participation in joint construction is concerned, could easily have introduced an element of doubt as to the success of the project.

An effort has been made in this brief paper to touch on a few of the problems which will come up for adjudication by those who endeavor to undertake similar projects in joint construction. The suggestions contained herein are the result of five years of development under parctically all conditions, and it is hoped that it will be possible for others to inaugurate a system which will solve even better the problem of complete cooperation between utility corporations.

Possibly there are some operating engineers who will find it impossible to secure the cooperation of kindred or opposing interests in such a project. Public opinion is an excellent but uncertain regulator in this respect, and it is to be regretted that some corporations are glad to be publicly coerced into propositions which should have been adopted as sound business policy.

However favorable we feel toward public control, matters of equity, as between the corporations themselves, should be adjusted on an equitable basis without great legal assistance or the compelling influence of a public service commission.

There are few cities in the United States where conditions are favorable for complete underground distribution systems as a possibility of the immediate future. To attempt to accomplish even a small portion of this would be to invite possible financial difficulties. But we can and should make our overhead construction conform to certain limits of decency.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Portland, Ore., April 16-20, 1912.

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(Subject to final revision for the Transactions.)

ARC VS. TUNGSTEN STREET-LIGHTING IN SMALL TOWNS

BY C. E. STEPHENS

PURPOSES

Early in the 15th century street lights were ordered in Paris, France, to prevent crimes of violence. This was at a time when the only occupants of the streets after night were belated pedestrians and a few vehicles. In the present day the use of our streets by night is growing and ever increasing. In fact the traffic in certain sections is heavier, in some cities, during the earlier part of the evening than it is at any time during the day. It is necessary to provide street illumination to mark the course, assist the police, also to avoid obstacles and to recognize persons. Police require to observe suspicious characters, and to see numbers on automobiles.

It is difficult to estimate the value of good street illumination, nevertheless it is positive. The best lighted streets attract the largest crowds. An increase of intensity of illumination increases the traffic, and property values fluctuate with the density of the crowd. It is a noteworthy fact that, in many of our cities and boroughs, one street or section thereof, or perhaps one side of a particular street, is congested with traffic, while other sections in the immediate locality are practically deserted. In some cases this can be attributed to the character of the business houses,but in a large proportion of the cases, there is no doubt that the illumination of the several sections is responsible for the condition. There is, therefore, at the present time a far closer relation existing between public safety and adequate street illumination than existed two or three hundred years since.

The appearance of our streets gives the visitor a favorable or unfavorable impression of the city's thrift, depending very largely upon whether or not the illumination is adequate. Well lighted streets have a wholesome appearance which is an incentive to cleanliness.

Very little need be said to convince the average citizen of the positive value of well lighted streets. It remains, therefore to profit by the experience with the various systems in use and to select the one which more nearly fulfills the requirements of local conditions.

In this connection we may mention some of the defects in the present practice. There is no doubt but that as a whole, street illumination in American cities is inferior to that of European cities. This is generally understood to be for the reason that European cities have a far greater number of inhabitants per square mile than do American cities, and a lower cost for labor and material in properly maintaining a lighting system, both of which combine to reduce the proportional cost per inhabitant of lighting the street. We believe the chief cause to be that the American public has not been educated to the value of an improved standard of street illumination. This standard has increased wonderfully within the last five years, but there is room for great improvement. A greater number of lamps in some cases, and in others larger candle-power units, have been installed as a result of a spirit of cooperation among the lighting companies.

The principal defects in the past have been the absence of a properly diffused light and the use of high brilliancy units so placed as to violate the physiological requirements for satisfactory street illumination. This applies particularly in sections where the cost prohibits any class of illumination other than that of a lamp used for a marker.

Until within the last few years, very little attention has been given to scientific illumination, either in commercial, industrial, residential or street lighting. The first improvements were made in the industrial and commercial field. The progressive and successful industrial and commercial concerns soon realized the necessity for better artificial illumination, in order to improve the quality, and increase the output and efficiency of their organization. This resulted in an application of scientific principles of illumination in their establishments which has been followed to a limited degree in residential lighting.

The long period of insufficient and generally unsatisfactory illumination of the streets, is now being succeeded by a period in which central stations, civic organizations and merchants are making a gigantic effort to improve conditions. This effort has resulted in the installation of a large variety of lighting systems.

Great progress has been made in educating the general public to a higher standard of street illumination. To a limited degree they have begun to realize the inestimable value of a higher standard of illumination. We have installations worthy of considerable praise, but as yet the improvements of which we boast do not compare favorably with the standards set in other lines of civic betterment.

GENERAL CONDITIONS

The fundamental problem to consider in the illumination of any street is the intensity of the illumination required and its production at a minimum cost. The cost includes the expenditure of energy, cost of maintenance, and interest and depreciation of the lamps, plant and all auxiliary equipment.

The area to be lighted is a long and comparatively narrow strip.

The intensity of illumination is proportional to the light intensity of the unit and inversely proportional to the square of the distance from the light source. Assuming that for a given minimum illumination a certain distance between lamps is required, if this distance be doubled, each unit must have four times the light flux and each mile of street will require two times the energy. Inversely, if the distance between units be reduced one-half, to get the same minimum intensity of illumination will require only one-fourth the light flux and one-half the energy. If the problem could be solved on an energy basis alone, it would therefore be logical to use a maximum number of light units with a corresponding reduction in their flux and energy consumption. It will be noted, however, that increasing the number of units also increases the installation and maintenance cost of the system. There is a point beyond which the cost for any increase in the number of units will exceed the saving in energy consumption. A point cannot be fixed which will apply generally on account of the innumerable variables (such as the intensity requirements in different sections of the city, obstacles which prevent a proper location and distributions of lamps, energy costs, etc.) which are involved.

When considered from the standpoint of economy without regard for illumination and decorative requirements, if energy cost is low, large units at great distances apart are better, and if energy cost is high, small light units placed at frequent intervals are more economical.

It should be noted that the above applies only to the illumination of long and comparatively narrow areas where the flux of light required varies with the distance between units, that is, when the distance between the units is doubled, the area which a particular lamp must light is only doubled. This does not apply in the illumination of large rectangular areas where the light units are placed on the basis of the square, since under these conditions when the distance between units is doubled the area which each unit must light is increased to four times, the total light flux is increased four times, (to maintain the same minimum intensity of illumination) and the efficiency remains the same.

In street lighting, therefore, to keep cost within reasonable limits the intensity of illumination is necessarily very low. Heretofore we have had to be satisfied with a spot light form of illumination in our streets, but recent improvements in efficiency and the satisfactory operating characteristics of our most modern street illuminants make it possible to light our streets economically and comfortably by night. The increased standard of illumination of the street has become necessary on account of the extensive use of our streets at night. The character of this illumination is general as distinguished from local lighting, and on account of the low intensity should be quite uniform or else effective illumination midway between lamps will be further reduced by the points of high intensity immediately under the lamp.

Having mentioned some of the general requirements of street illumination, it is in order to discuss conditions, quantity and quality of the light and to note its relation to intensity.

The requirements for good street illumination may be considered under the following heads:

Uniform intensity; distribution.
Diffusion.
Intrinsic brilliancy of light source.
Shadows.

We see things by virtue of their difference in luminosity. Difference in color at low intensities is barely discernible, and regardless of the quantity of light received by objects, the difference in the amount reflected to the eye from black objects and bright objects is comparatively small. That is, a black object will reflect approximately 25 per cent of the light reflected by a bright object. The ability to perceive objects, therefore, depends upon the capacity of the eye to distinguish differences in luminosity. According to Fechner's law the eye can perceive, over a wide range of intensity, a fairly constant fractional difference in luminosity. In bright light it ranges from one-half of one per cent to one and three-fourths per cent. This difference decreases with light intensity until at one lux the eye is hardly able to perceive shadows. The ability of the eye to perceive differences in luminosity depends largely upon the condition of the eye. If the eye is adapted to the dark, shade perceptions are possible at extremely low light intensities.

In street lighting if you can see an object fairly well between lamps, *i.e.*, at the point of minimum light intensity, the ability to see is materially affected by glare, and to changing of light intensity due to moving along the street. It is of importance, therefore, to provide a uniform intensity of illumination, particularly in streets where intensity is low, and to select, equip and locate the light source to avoid glare.

By uniformity is meant a uniform illumination at all points throughout the length of the streets. At street intersections and other points where traffic is likely to be congested a higher intensity of illumination is needed. The intensity at these points can be ten times that of the minimum illumination at other points and not be objectionable, since there are no moving vehicles which will approach alternate light and dark spots so fast but that the eye cannot easily accommodate itself to the different intensities of illumination. Assuming the minimum intensity of illumination as unity, the ratio between maximum and minimum illumination for business or other sections of the street where a high intensity is maintained, should not exceed ten to one. For residence sections, parks and outlying districts the ratio should not be greater than five to one. This ratio of maximum to minimum illumination is smaller in the latter case because of the fact that where intensities of illumination are quite low the effect of the comparatively light and dark spots produces objectionable glare. Furthermore, it is in these sections of our streets that are found the fast moving cars, automobiles and carriages. Uniformity is of greater importance, therefore, in the residence or other sections or cities where low intensities of illumination prevail, and of less importance in the business sections where high intensities are used.

To produce a uniform intensity of illumination on a horizontal plane, a certain intensity of distribution curve and a certain location of light sources is required. The uniformity of illumination with a given unit varies with the distance between units and their height. The very nature of the street area determines that the light units must be in a single or double row along the street. The number and size of units and height of units are determined by the intensity requirements and cost of operation. In making a selection of units for a given condition it is necessary, therefore, to carefully consider the curve of light distribution of the available units. Increasing the height of the lamp decreases the intensity of illumination directly under the lamp quite rapidly and does not materially change the intensity at greater distances from the lamp. The height of a lamp is usually quite limited on account of the extremely high cost of installation, maintenance, tree obstruction, etc.

A long experience with the old open arc lamp has demonstrated that in any illumination scheme it is objectionable to use a source from which the light flux issues from a point. This is particularly true in street lighting where relatively large units are employed, since it is impracticable to support a lamp at such a height that it will not come within the field of vision at a time when the observer is quite near the lamp. It is not feasible to change the nature of the light source, but by an intelligent use of the available glassware for modern street lighting units it is possible to diffuse the light quite satisfactorily. The most objectionable features of an improperly diffused light are the high intrinsic brilliancy and the resultant sharp shadows cast by the illuminated objects. The extreme brilliancy of an improperly diffused light, when within the field of vision, causes a contraction of the pupil of the eye and produces the same physiological effect as if the intensity of illumination were reduced. There is considerable loss in light flux when a diffusing medium is used (due to absorption), but the final result will ordinarily be far superior because with the reduced light flux a greater proportion of the light will enter the eye.

The shadows of an object when illuminated by directed light are very sharply defined and terminate abruptly. This is particularly noticeable in street lighting where they are exceptionally long and project lengthwise of the street. This is very objectionable from the standpoint of proper illumination in that it makes it quite difficult to clearly distinguish the outline of small obstructions, magnifies the size of the object, and the result is unsatisfactory illumination. To minimize this effect demands that a source of light should be thoroughly diffused (issue from a large source) in order to prevent sharp shadows, and be as high above the point as possible in order to avoid excessively long shadows.

CLASSIFICATION OF STREETS

The wayfarer wants to distinguish the shadow of a post from a hole in the ground; and the policeman to distinguish a peaceable citizen from a burglar. In some sections it is desired to distinguish faces, read addresses, house numbers, etc. It therefore becomes necessary to classify the lighting undertaken and to light each street according to its needs, keeping in mind the class of traffic by night and the requirements of public order.

In small towns the streets which require first-class illumination are public squares, the principal business streets, the streets leading to a railway station where vehicles and pedestrians are numerous, and certain sections of streets where crime abounds.

The streets which require second-class illumination are those where nocturnal traffic is light or moderate. Such streets are the quiet residence streets, the business streets on which there is little traffic by night, and the outlying streets which are the principal thoroughfares to and from the country or neighboring towns.

The streets which require third-class illumination are those in the outlying portions of the town, perhaps not built up, but are within the city limits.

In small towns or cities very little first-class illumination is required, since the traffic is rarely very dense and the area of the streets under this classification is comparatively small. The intensity of light required is lower than in similar sections of larger cities, and from a physiological standpoint there should be sufficient reading illumination for a minimum value. This intensity is usually set at approximately 0.8 average, with a minimum of 0.4 lux. The standard of intensity of street illumination has been steadily rising in this country, and the small town has found it difficult, owing to the large amount of street mileage compared to property values, to keep up with the pace.

The intensity of light required for second-class streets should be sufficient to read an address and to see house numbers, and should be an average of 0.4 with a minimum of 0.25 lux.

The third class of illumination should be sufficient to avoid other wayfarers and objects. No attempt can be made to illuminate the street but markers should be provided at street intersections.

Light Sources Available

The subject of this paper excludes all forms of light sources except the arc lamp and the tungsten incandescent lamp.

Arc lamps may be divided into four types; 1, open carbon arcs; 2, enclosed carbon arcs; 3, metallic flame or luminous arcs; and 4, the enclosed flame-carbon arcs. The first two types have become practically obsolete as street illuminants. The metallic flame arc has largely replaced the older forms of lamps. The color of the light is white and the distribution shows a maximum candle-power from fifteen to twenty-five degrees below the horizontal. The electrode life averages from two hundred to two hundred and fifty hours, and the maintenance cost is comparatively low. The efficiency of light production varies from one-half to one watt per candle, depending upon electrode life and glassware equipment. The lamp is operated at from four to seven amperes, with an arc voltage of about seventy. It operates only on direct current and is ordinarily used on series circuits from constant-current rectifiers.

The flame-carbon arc lamp has superimposed carbons, which give a life of from 100 to 125 hours. The carbons are impregnated with a light-giving salt which furnishes a white or yellow light. The light distribution shows a maximum at from 20 to 30 degrees below the horizontal, similar to the metallic flame, which adapts it admirably for lighting streets or large areas. The volume of light is considerably in excess of the metallic flame lamp, and the efficiency of light production averages from 0.2 to 0.3 watts per candle. This lamp is the most efficient light source available for street illumination. It has been recently marketed in this country for operation on all commercial circuits, both alternating and direct current. For street illumination a series design is ordinarily used.

The tungsten incandescent lamps are available in sizes ranging from 40 to 400 candle-power. The efficiency of light production is approximately 1.2 watts per candle. The light distribution, when properly equipped with reflector, shows it fairly well suited for street requirements.

An ideal curve of light distribution, from a practical standpoint, for a street lighting unit, is one having a maximum candle power from twenty to thirty degrees below the horizontal, and a rapidly decreasing candle-power value above and below these angles. By a practical standpoint we mean, when considered from the power available, the limits to the height of the lamp, and the nature of the area to be lighted.

The question of whether arcs or tungsten lamps should be used in the illumination of the streets in a small town is the old question of whether large or small units are best. In our opinion each unit has its own field of usefulness, and the requirements of the small town involve both the arc and tungsten incandescent lamps. When considered from the standpoint of illumination, a larger number of small units have the advantage in that the total intensity required to meet the conditions of maximum and minimum values is lower than for large units. It is not desirable, however, to solve the problem from the standpoint of maximum and minimum illumination alone for there are other items which materially affect the result. Chief among these is the limit to expense involved in erecting and maintaining a large number of units; the areas beyond the streets which are lighted by a larger unit; and the amount of light reflected from buildings to the street surface when large units are employed. In other words, if one large unit be replaced by a number of smaller units, under the same conditions, a reduced total light flux for the same minimum illumination is secured, but it is necessary to install and maintain a larger number of units. It is possible, therefore, that no gain in illumination efficiency is made which is comparable with the loss in light flux. Small units have a large field in second and third-class lighting, and large units in first-class lighting.

About three years ago there was started the tungsten post system of street lighting for the streets requiring first-class illumination. This system was installed quite extensively throughout the country, but recent practice indicates a logical tendency to use flame arc lamps, supported at greater heights from the street surface.

For a time the tungsten post system was a novelty and attracted considerable attention, but its disadvantages are numerous. It is impractical to supply power to the tungsten post system from overhead feed wires. This necessitates the tearing up of both sides of the city streets to install underground feed wires, which therefore makes the first cost of the installation excessive.

The first cost of underground feeders for the tungsten post system, if constructed in an approved manner, would be prohibitive. The construction is therefore necessarily a temporary job of underground work, and in case the system is unsatisfactory, or for any reason is discontinued, the underground feature would be useless.

The tungsten post system involves the erection of a large number of additional posts on the street which are unsightly and which give a "fenced in" appearance to the street.

The tungsten posts are comparatively low, since the lamps are approximately only 12 ft. (3.6 m.) from the surface of the street. The light from the lamps is therefore constantly in the line of vision and produces a glare effect in the eye that from the standpoint of good illumination is extremely objectionable. The general effect on the public may be pleasing at the start, but experience shows that after a short time the novelty wears off and general dissatisfaction prevails.

The annual maintenance cost of the tungsten post system is excessively high and it demands constant daily attention.

We see no excuse for a cluster of tungsten lamps to provide a large unit, when the arc lamps provide such an excellent substitute with superior illumination results and a lower maintenance cost.

The flame arc system is simple and inasmuch as the lamps are controlled from the light plant and are trimmed and cleaned at regular intervals, little attention is required. The lamps give a large volume of light and when placed about 25 ft. (7.6 m.) from the street surface give a uniform distribution of light and do not produce the objectionable glare which is characteristic of the tungsten post system.

In lighting the second-class streets in small towns, trees are often encountered which prevent the use of large units. It is necessary to place the lamps low, in order to clear these obstructions to the light rays; and this low mounting height in turn determines the use of a small unit such as the tungsten lamp affords.

In deciding on the unit to be used, the choice lies between the arc and the tungsten lamp. Once the choice is made, it is then a question of spacing the lamps to give the minimum illumination and of mounting them at such heights as will eliminate glare.

The principal defect noted in a large number of arc lamp systems is the tendency to support the lamps too close to the ground. This is particularly objectionable on account of the fact that the glare effect produced by the bright light in the eye, causes a contraction of the pupil, which limits the amount of light entering the eye and no advantage is gained by a high intensity of illumination.

SUMMARY

From the above discussion, it will be noted that local conditions practically determine the unit to be used. No one unit can be adopted as being the best for all installations. Assuming that all small towns have a certain amount of first, second and third class lighting, it will be necessary to use both arc and tungsten units. If the number of arcs is large enough to admit of installing one complete circuit, use can be made of either the metallic flame or flame-carbon lamps. If, however, only a small number of arcs are required, it may be advisable to use the alternating current flame-carbon arcs and operate them in series with the tungsten lamps in the residence sections.

For the second and third-class lighting, the tungsten lamp is better adapted. It is possible to operate them in series, using small units between intersecting streets and larger tungsten or perhaps arc lamps at street intersections. In any case it is advisable to raise the lamps at street intersections, in order to indicate to the driver of a fast moving vehicle that he is approaching a cross street. Long lines of lamps on the same level, particularly if they are low, tend to confuse one in rapid motion and it is difficult to see a cross street and to observe vehicles emerging from same.

Perhaps the most fertile field for immediate development is in a rearrangement of the present lighting system. It is possible to make enormous improvements an almost any system of street lighting by relocating the lamps; raising them higher from the street; removing useless, and replacing crooked, or decayed poles; and giving the lamps and fixtures sufficient attention to insure a pleasing appearance. A recent example of what can be accomplished along this line is an installation of an ornamental street lighting system of arc lamps. The novel feature of the installation is the use of the iron trolley poles for supporting the lamps. The poles were reset, where necessary, to make them perpendicular to the street surface, and a suitable iron extension post securely fastened to the top of the trolley poles. The length of this extension post was adjusted to give the lamps a uniform height of 26 ft. (7.9 m.) from the street. Substantial mast arms were designed to support the lamps from the extreme top of the poles, and the service wire is carried overhead on high voltage insulators.

Mention may also be made of the possible improvements in caring for lamp glassware. Street lamps are subject to most severe weather conditions; dust and smoke will in a very short time have a deteriorating effect on the appearance of a lamp. A large proportion of industrial and manufacturing plants, stores, etc., have realized the advantages of keeping lamp globes and reflectors in good condition, and have had the maintenance department adopt a regular schedule for frequently washing and cleaning the fixtures. The results obtained have been highly satisfactory.

A street lighting unit is the one piece of electrical apparatus which is constantly in the public eye. Its appearance largely influences the attitude of the general public toward the lighting company. Why, then, should it not be kept in first-class condition?

It is a matter of note that while the central station managers have taken advantage of the many refinements in power station designs, have so regulated the power demands that the revenue is a maximum for the minimum station expense and have installed the very best generating equipment available, they have only quite recently turned their attention to the efficiency of the distributing lines and lamp fixtures which are just as essential to the successful operation of a lighting system.

No doubt the central stations have been greatly handicapped in their efforts to improve street lighting condition by the vast amount of unreliable data which is frequently published. We often read articles in local papers in which the rates for street lighting service in various cities and towns are compared. These articles appear quite frequently during the time when a new contract between the light company and city is pending, and are sometimes very inaccurate and misleading. The data are generally inaccurate, not in the information given, but in the lack of complete information.

Local conditions again are responsible for the excessive variation in street lighting rates. In some cases a very low rate is given by a municipal plant, because of the fact that the accounting methods used do not take into consideration all of the items properly chargeable to the service. Maintenance and depreciation on distributing and plant equipment, interest on investment, pole taxes, etc., are often neglected. Other items, such as coal, water, etc., in combination water and light plants, are charged to other departments of the city government. The result is a very low rate for street lighting service which does not represent the true cost.

In other instances, central stations make a very low rate for street lighting service, in exchange for a long term franchise for commerical light and power privileges. Another city secures a low rate for street lighting from a central station enjoying water power privileges, which conditions are not justly comparable with rates from another central station, perhaps many miles from a coal and water supply.

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DOES IT PAY THE AVERAGE COAL MINE TO PURCHASE CENTRAL STATION POWER?

BY GRAHAM BRIGHT

In the application of central station power to coal mines the successful operator of today is sometimes at a loss to know just what saving will be effected, for the following reasons: first, he believes that he is producing power at a fairly low cost, due to cheap fuel, simple apparatus and low cost of buildings; second, not knowing approximately his costs in detail, he is at first unable to see his saving, if any, as compared with a definite rate per kw-hr. for central station power; third, the use of central station energy often requires the purchasing of new apparatus, and the selling of the present generating apparatus under unfavorable conditions.

In regard to the first reason, the cost of fuel is, of course, low at the mine, but its value should be figured at the price that could be obtained for it if sold. The water question is often a serious one, and bad water in many cases occasions heavy repairs. The boilers, engines and generators as a rule are the simplest and cheapest obtainable, there being very little incentive for high economy at a mine power plant. Reliability is the first requisite. and with the class of skilled help obtainable about a mine, this reliability can be obtained only with the simplest kind of apparatus. The buildings are generally of the cheaper construction, and often have inadequate illumination, in which case the equipment does not receive the care it should.

In regard to the second reason, a certain rate per kw-hr. for power from a central station is not always an indication to the average operator as to what his total cost for power and his saving will be.

In regard to the third reason, in order to utilize central station energy it is usually necessary to purchase motors to replace the fan, hoist and compressor engines, and to purchase synchronous converters or motor-generator sets to replace the generators and engines driving them. The boilers, engines, pumps, old generators and piping must be sold and it is rather difficult to get much more than scrap value for these, if they have been in use for several years. If the proper depreciation on the old apparatus has been charged off each year, the value carried on the books should not be very high. The difference between the value of the old apparatus and the salvage obtained for it must be charged off, or the entire value of the old apparatus must be charged off and the value of the new apparatus put on the books as the difference between the cost of the new apparatus and the salvage obtained for the old. To provide for this change new capital is required, and the members of the average board of directors must be assured of adequate returns before they will permit the expenditure of this new capital.

The purpose of this paper is to show a method of obtaining the cost of power at an average coal mine with its own power plant, and what the cost would be if central station energy were purchased at some definite rate per kw-hr. The values assumed are only approximate, as it is the method that is to be shown rather than actual values.

We will suppose that we are investigating a shaft mine, having the following list of power apparatus:

4 return tubular boilers, 18 ft. by 72 in. (549 by 183 cm.) Steam pressure, 90 lb. (40.8 kg.).
2 boiler feed pumps.
1 deep well pump.
1 feed water heater.
1 double balanced steam hoist. Max. h.p. of engine, 400.
1 ventilating fan. Horse power of engine, 50.
2 high-speed 150-h.p. engines for generators.
2 100-kw. 500-volt d-c. belted generators.
1 10-h.p. engine for machine shop.
1 10-h.p. " " screen.
1 25-h.p. " " elevator.
1 5-h.p. " " coal conveyer to boiler room.
2 steam pumps at bottom of shaft, 10 h.p. each.

The motors operated from the generators will have a combined capacity of about 500 h.p. The generators will be operated about twenty hours per day, the time depending upon the amount of electric pumping to be done. Some of the coal cutting is frequently done at night, which tends to improve the load factor on the generators, the lights and pump load being, as a rule, a small percentage of the capacity of one generator. The hoist will operate eight hours per day, with an occasional trip at night, or on non-working days. The fan will operate 24 hours per day. The tipple engines will work eight hours per day, and the steam pumps and coal conveyor will work intermittently.

The mine under consideration has an average output of 1,100 tons* per day, and operates on an average 18 days per month all the year round. On days that the mine does not operate, one generator must be run to supply power for the pumps, lights and locomotives doing special work.

The operating force will consist of the following:

1 day engineer for the hoist.
1 " " " " electric plant.
1 night " " " " "
1 day fireman
1 day fireman's helper for wheeling ashes and helping around boiler room.
1 night fireman.

The wages of extra repairmen will be included in upkeep and repair charges.

The amount of coal used under the boilers will be about 500 tons per month, and this coal being slack, or a mixture of nut, pea and slack, its value will be about fifty cents per ton. In some plants it is necessary to use run-of-mine under the boilers, in which case the value is considerably higher.

To obtain the cost of power per kw-hr., it is of course necessary to first find out how many kilowatt-hours per day or per month are being produced. It is best to figure the costs on a monthly or yearly basis, in order to take into account the time lost when the mine is not operating. The cost per ton output for power will depend somewhat on the number of days per month or per year the mine operates, since a number of the items of expense go on just the same whether the mine operates or not. In this paper the costs will be figured on a monthly basis, taking the working days as the average per month for a year.

When obtaining the total kilowatt-hours the load factor should be determined at the same time, since the rate of charge by the central station often depends upon the load factor. The load factor should be figured on the total five-minute or some other short time peak rather than on the capacity of existing machines, since the engines and generators installed are often very much larger than necessary, and their capacity is seldom reached by even momentary peaks.

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*1 long ton = 1.01605 metric tons.

The electrical kilowatt-hours, momentary and five-minute peak loads can easily be obtained by placing a watt-hour meter and graphic recording wattmeter or ammeter in the circuit of the generators for a 24-hour run, both for a working and a non-working day. The power developed by the steam engines driving fans, hoists, etc., is more difficult to obtain. If possible, these engines should be indicated, and from the cycle of operation, the horse power-hours or kilowatt-hours can be computed for a working and non-working day. Where it is not possible to use an indicator, the power taken by the fan engine may be calculated approximately from the size and speed of the engine, steam pressure, size and speed of fan, air pressure, and volume of air in cubic feet per minute. The power required by the hoist can be figured from the work being done and checked by the size and speed of the engine and the steam pressure. It is best to place the information in tabular form, so that ready comparison may be made. Table I shows the method of obtaining the total kilowatt-hours per month and the load factor.

TABLE I.—CAPACITY, KW-HR. AND LOAD FACTORS.

Machines	Five-min. peak	Capacity in kw-hr. 24 hr.	Actual kw-hr. for 24 hr.	Capacity in kw-hr. 30 days.	Actual kw-hr. for 30 days.
Generators	150	4,800	800	144,000	19,200
Fan	40	960	680	28,800	18,000
Hoist	60	1,440	336	43,200	6,080
Elevator	20	480	160	14,400	2,880
Screen	5	120	40	3,600	720
Machine shop	5	120	40	3,600	1,200
Conveyer	1	24	8	720	160
Pumps	12	288	120	8,640	2,400
Total	293	8,232	2,184	246,960	50,640

Load factor for 24-hr. working day = 26.6 per cent.
" " " 30 days = 20.6 per cent.

In the first column are listed the various machines that are developing power. The second column gives the five-minute peak load for each machine. It will be noticed that for the generators this peak is less than the capacity, but this is almost universally the case in mine power plants. The fan engine runs at one speed during 10 hours of a working day, and at a speed requiring about one-half as much power for the remaining 14 hours, and for 24 hours of a non-working day.

The hoist has a peak load of about 300 kw. for five seconds, followed by a load of about 150 kw. for five seconds. The average time required for each trip will be about 52 seconds, but for intervals of several minutes, this time may be as low as 35 to 38 seconds. The five-minute peak is the average kilowatts for five minutes, with the hoist working at its maximum speed. At the average speed, this peak will be about 42 kw.

The third column shows the capacity in kilowatt-hours of each machine if it works 24 hours. The fourth column indicates the actual kilowatt-hours during a 24-hour working day. The ratio of column 4 to column 3 designates the load factor for a 24-hour working day. Column 5 shows the capacity in kilowatt-hours for 30 days, 24 hours per day. Column 6 shows the actual kilowatt-hours for 30 days. This column is made up of the figures of column 4 for 18 days, plus the kilowatt-hours for 12 non-working days. The ratio between the values of column 6 and column 5 gives the load factor for 30 days. The load factor of a mine plant depends largely on the amount of fan and pump load, and may vary from 13 to 40 per cent.

Table II shows the elements entering into the assumed installation together with the possible savings in these elements when power is purchased.

The interest, depreciation, repairs and upkeep are indicated for each part of the power plant. No saving is figured on the engine building, since it will probably be used for the new motor-generator and switchboard. This apparatus should be so placed that the hoist engineer can look after its operation during the day. For the night shift a man can be obtained for about $60 per month.

In some cases where the generators are modern it may be advisable to retain these generators and purchase motors to drive them. As a rule, the average load on a mine generator is very much below its rated capacity. The peak loads are, however, rather high, so that the generators are really selected in regard to the peak rather than the average load. The type of load curve obtained on a mine generator is shown in some graphic charts in the paper, in the March PROCEEDINGS of the Institute, entitled "Central Station Power in Coal Mines," by W. A. Thomas. The older types of machines will not stand

TABLE II.

Cost Based on One Month of 30 Days.

Items Included in Cost.		Total present cost.	Amt. saved with purchased power.
Three engineers at $85.00		$255 00	$110 00
Two firemen at $75.00		150 00	150 00
One helper at $50 00		50 00	50 00
500 tons of coal at 50c per ton		250 00	250 00
Oil, waste and packing		50.00	40.00
Boilers:			
Cost, including stack	$4,000 00		
Feed pumps	200 00		
Setting and foundation	800 00		
Feed water heater	400.00		
	$5,400.00		
Interest at 5 per cent		22.50	22.50
Depreciation 7 per cent		31.50	31.50
Repairs and upkeep		50 00	50 00
Insurance		10.00	10.00
Boiler Building:			
Cost $2,000.00			
Interest at 5 per cent		8.35	8.35
Depreciation at 5 per cent		8.35	8.35
Upkeep and repairs		5.00	5.00
Engines:			
Cost Two generator engines	$3,000.00		
Hoist engine	1,500.00		
Fan engine	600.00		
Elevator engine	200.00		
Screen engine	150.00		
Conveyer engine	100.00		
Pumps	400.00		
Machine shop engine	150.00		
	$6,100.00		
Interest at 5 per cent		$25.40	$25.40
Depreciation at 6 per cent		30.50	30.50
Upkeep and repairs		30.00	30.00
Building:			
Cost $2,500.00			
Interest at 5 per cent		10.40	
Depreciation at 5 per cent		10.40	
Upkeep and repairs		5.00	
Piping:			
Cost $1,500.00.			
Interest at 5 per cent		6.25	6.25
Depreciation at 7 per cent		8.75	8.75
Upkeep and repairs		15.00	15.00
Generator, switchboard and wiring:			
Cost $2,640.00			
Interest at 5 per cent		$11.00	$11.00
Depreciation at 5 per cent		11.00	11.00
Upkeep and repairs		15.00	15.00
Superintendence		25.00	
Taxes at 1 per cent. of valuation (assessment 90 per cent.)		15.00	7.50
Liability insurance at $1.33 per $100.00		6.05	4.15
Overhead		50.00	
Total cost		$1,165.45	$900.25
Fixed charges		284.40	
Operating expenses		881.05	

peak loads much beyond their rated capacity, and even if they would, the engines are seldom in condition to take care of these loads. This characteristic of the engines is really a blessing in disguise for the generators. A modern commutating pole generator driven by an induction or synchronous motor can be purchased to give 100 per cent overload for short periods with little or no drop in speed and with good commutation. The retaining of the old generator would require a foundation for the motor, a belt, a coupling and probably an extension to the building. The total cost will about equal the cost of a new motor-generator set, while the latter will be a much more satisfactory combination. Synchronous converters are also used instead of motor-generator sets, depending upon the local conditions.

The item "superintendence" includes that part of the salaries of the master mechanic and superintendent chargeable to the production of power at the mine in question.

TABLE III.

COST OF NEW EQUIPMENT.

1	150-kw. motor-generator set	$2,800.00
1	switchboard	150.00
1	75-h.p. induction motor with starter for fan	950.00
1	250-h.p. " " " control " hoist	2,500.00
1	30-h.p. " " " starter " elevator	400.00
1	10-h.p. " " " " " machine shop	170.00
1	10-h.p. " " " " " screen	170.00
2	10-h.p. motor-driven pumps	650.00
	Installing, including foundation, wiring and buildings	1,000.00
	Total cost	8,790.00

Taxes are figured at 1 per cent per year, on an assessment of 90 per cent of the valuation.

Liability insurance is figured on the pay roll.

"Overhead" includes that part of the salary of the officers and clerks of the company and of the office expenses chargeable to the production of power, and should be the same proportion of the total overhead that the cost of power is to the total cost of production.

The total cost per month is $1,165.45, of which $284.40 is a fixed charge and $881.05 the operating expense. The saving per month with purchased power is $900.25. Since the total of kilowatt-hours per month is 50,640, the total cost of power per kilowatt-hour is $0.023. The saving with purchased power will be $0.0178 per kw-hr. The difference between these values or $0.0052 is the common cost per kilowatt-hour, which will exist in either case.

In Table III is given a list and cost of the new equipment which must be purchased in order to utilize central station energy. Motors are provided to replace the present steam engines. All motors are alternating-current motors, and can be operated at any time, independently of the supply of direct current. In some cases it may be preferable to supply a direct-current motor for the hoist, in which event a larger motor-generator is required. This increase may be in the form of a larger generator or of two generators driven by one large motor. One of the generators would be used for the direct-current supply for the mine and the other, with special control, for the hoist. If possible, the old hoist should be sold complete and an entire new electric hoist installed. In the present case, an alternating-current motor will be substituted for the steam engine at the hoist. A variable speed alternating-current motor will be supplied for the fan. In many cases air compressors are used to supply air for punchers and pumps. It would be advisable to do away with air compressors entirely, and install electric cutters and motor-driven pumps, as the efficiency of the air system with its usual leaks is very low. However, in gaseous mines, it is sometimes considered dangerous to operate electrical apparatus, in which case a motor-driven compressor should be furnished.

TABLE IV.
SALVAGE ON OLD EQUIPMENT.

4 boilers with stacks		$400.00
2 feed pumps and water heater		90.00
2 150-h.p. generator engines		600.00
2 100-kw. generators with belts and switchboard		600.00
Engine part of hoist		50.00
1 elevator engine		50.00
1 fan engine		75.00
1 screen engine		25.00
1 machine shop engine		25.00
1 conveyor and engine		30.00
2 steam pumps		50.00
Piping		50.00
Total salvage		$2,045.00
Total net cost		6,745.00
Interest at 5 per cent for 1 month	$28.00	
Depreciation at 5 per cent for 1 month	28.00	
Upkeep and repairs	15.00	
Total	$71.00	
Operating and fixed charges per kw-hr. for new equipment		$0.0014

One thousand dollars has been allowed in Table III for the installation of the new apparatus. This should be ample to provide for foundations, alterations in building, wiring and mechanical application. The total cost is $8,790.

In Table IV is shown the probable salvage that could be obtained for the old apparatus. These estimates should be kept rather low, since it is sometimes difficult to get good prices for old apparatus. The total salvage amounts to $2,045. The net cost of new equipment will, therefore, be $6,745. The interest, depreciation, upkeep and repairs on the new equipment will amount to $71.00 per month. This is at the rate of $0.0014 per kw-hr.

In Table V some specific costs and savings are given. The total cost of power per kilowatt-hour, saving per kilowatt-hour with purchased power, and the common cost in either case, as before mentioned, are first shown. If the common cost is added to the cost per kilowatt-hour with new equipment, we have $0.0066 as the total cost per kilowatt-hour with purchased power exclusive of the charge of the central station. If this value of $0.0066 is subtracted from the total cost per kilowatt-hour of $0.023, $0.0164 is obtained as the central station charge which would make the total cost of power the same as at present. In other words, if the central station rate were $0.0164 per kw-hr. the total cost of power would be the same as at present. Any rate below $0.0164 will, therefore, represent a clear saving. At a rate of $0.0125 per kw-hr., the saving would be $0.0039 per kw-hr., or $2,375 per year, which is a saving of 35.3 per cent. over all charges on the new investment. At this rate, the change would pay for itself in less than three years. At a rate of $0.01 per kw-hr., the saving would be $3,890, or 57.8 per cent. At this rate, the change would pay for itself in less than two years.

TABLE V.—COSTS.

Total cost per kw-hr. for power	$0.023
Saving per kw-hr. if power is purchased	0.0178
Common cost, in either case, per kw-hr.	0.0052
Net operating and fixed charges per kw-hr. for new equipment	0.0014
Total cost per kw-hr. with purchased power, exclusive of central station charge	0.0066
Charge per kw-hr. by central station which would balance present cost.	0.0164
Saving per year at central station rate of $0.0125 per kw-hr.	2,375.00
Percentage profit on net investment of $6,745.00	35.3 per cent.
Saving per year at central station rate of $0.01 per kw-hr.	3,890.00
Percentage profit on net investment	57.8 per cent.
Present cost per kw. capacity (5-minute peak) per year for fixed charges	$11.65
Present cost per kw-hr. for operating expenses	0.0174
Total cost per kw-hr. with purchased power at $0.0125 per kw-hr.	0.0191
" " " " " " " " $0.01 " "	0.0166

A coal operator will readily understand that in his isolated plant he will have certain fixed charges which will be practically the same whether his plant operates or not. His power cost can be divided into fixed charges and operating costs. A central station supplying power for his mine will also have a certain part of its total cost as fixed charges. In many cases the fixed charges of the central station will be less than the operator's own fixed charges. The logical basis upon which to charge for central station power would therefore be a certain fixed charge per kilowatt capacity of substation or kilowatt demand, plus a rate per kilowatt-hour which will be equivalent to the operating expense. In the present case, if the fixed charge were made $12.00 per year per kilowatt demand on a five-minute peak basis, the charge per kilowatt-hour would be $0.0067 to make the total cost equivalent to $0.0125 per kw-hr. With the fixed charge system the total cost per kilowatt-hour decreases with the amount of power used. This is an incentive for the operator to extend the use of power as much as possible.

TABLE VI.

General Data.

Average working days per month	18
Electrical kilowatt-hours per working day	800
" " " " non-working day	400
Total steam and electric kilowatt-hours per working day	2,184
" " " " " " " non-working day	944
Maximum electrical kilowatt demand, momentary peak	180
" " " " five-minute "	150
Maximum total steam and electric kilowatt demand, momentary peak.	450
" " " " " " " five-minute "	293
Capacity of generators	200
Total kilowatt-hours per month	50,640
Kilowatt-hours per ton output, based on 19,800 tons per month	2.56
Present total cost of power per kilowatt-hour	0.0234
Present cost per ton output for power	0.0588
Cost per ton output for power with central station energy at $0.0125 per kilowatt-hour	0.0489
Cost per ton output for power with central station energy at $0.01 per kilowatt-hour	0.0425

There are certain advantages that central station power has over isolated plants that cannot be measured in dollars and cents, and in most cases, even when the fixed charge is the same as the operator would have in his own plant and the charge per kilowatt-hour is equal to his own operating expense, it would still be greatly to his advantage to purchase central station power.

In Table VI is given some general information in regard to the results of the tests and investigation that should be made at a mine. The momentary and five-minute electrical peaks are obtained from the graphic records. These graphic records are very interesting and show clearly the extremely fluctuating nature of the load, as well as the low average load. The maximum momentary electrical load is often less than the continuous capacity of the generators. A modern commutating-pole generator of 100-kw. capacity would easily take care of the load where two 100-kw. old type machines are used at present. A 150-kw. generator has been figured on to allow for the additional load of the pumps when changed to electric, and also to provide for future extensions. The information given in Table VI will serve as a guide for the central station in determining the capacity of its lines, transformers, meters, switches, etc. The power required is 2.56 kw-hr. per ton mined. Since the cost per kilowatt-hour is $0.0234, the present total cost of power per ton mined will be $0.0588.

Summarizing the above information, the following reasons are given to prove the advisability of a mine's purchasing central station energy rather than generating its own power.

1. Lower cost of operation.
2. Worry and care of power plant removed. The legitimate business of a coal operator is to mine and ship coal, and he should not try to carry on another business of so different a nature, at the same time. The efficiency of his plant will be greatly increased if he can spend his entire time in looking after the mining and shipping of the coal.
3. Reliability, which means greater production.
4. Much less expense involved in shutting down mine.
5. Capital needed for new power plant can be used for new development.
6. Increased output and additional power can be obtained quickly with small increase in capital.
7. Increase of production on account of increase of efficiency, due to ample power at all times.
8. No change in speed of fan and pumps due to steam pressure falling occasionally.

About the only disadvantage is that additional capital is often required with which to purchase new apparatus, but when the large returns in the shape of decreased operating expenses are shown, this capital is not difficult to obtain.

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MOTOR AND CONTROL EQUIPMENT OF ELECTRICALLY OPERATED VALVES

BY H. M. GASSMAN

Valves of 24 in. (60 cm.) diameter and larger are usually operated other than by hand for the reason that generally such valves must be closed in a very short time, which is impossible by hand operation, and also because such valves are frequently located in out of the way places and more conveniently controlled from some operating point more or less remote from the valves.

As large valves usually control very important service connections it is essential that the electrical equipment of such valves be dependable. Any failure of the valve operating equipment will occur, or at least be discovered, at the critical time when it is most needed. To guard against such failures valves should be inspected and tried out regularly, particularly where they are likely to remain in one position for long periods.

As the design of valves varies so much with the make, size and type this paper will be concerned with a statement of the operating conditions to be met in a general way and the principles which should govern the design of the equipment particularly of large gate valves for water and steam connections. From a mechanical point of view it is necessary to consider the maximum torque which can be exerted by the motor and design the gearing and attachments accordingly.

With large valves the proportion of maximum motor power to mechanical strength of valve and its mechanism is greater than in small valves, hence more attention should be given to the control and equipment of large valves.

The power required to open a valve is a maximum when starting the valve from its seat. After the gate has been opened, say one-fourth, comparatively little torque is required to complete the operation. The proportion of starting to running torque varies with the construction of the valve, the amount of corrosion and the condition of the valve seat. When closing hydraulic valves under pressure, the starting and running torques are comparatively small until the valve is about three-quarters closed. From that point on, the pressure on the gate increases approximately as a square of the decrease in the opening, consequently the torque at closing in such cases increases rapidly but does not reach the value of the starting torque required to open the valve under the same pressure conditions.

To overcome the sticking of the valve when it is to be opened, the drive is sometimes provided with a lost motion device so as to give a hammer blow when starting the valve from its seat. With a-c. motors such lost motion also allows the motor to develop a high speed and therefore a greater torque before starting the valve from its seat.

Unless some provision is made for limiting the torque of the motor or controlling the circuit when closing the valve it is possible to jam and injure the mechanism of the valve, making further operation difficult. A slip gear cannot be used for this purpose as the slipping torque in opening will be practically the same as when closing, unless the slip gear be designed to act in the closing direction only. Such a device might also prevent injury to the valve seat should some obstruction be in the valve at the time of closing.

The motor drive is usually designed so that the valve can be opened or closed in two to five minutes and a hand operating mechanism also provided by which the valve may be opened, in 15 to 45 minutes. A mechanical or electrical indicator should be provided to show the position of the gate, particularly when closed. Valve stems are often twisted off in an attempt to close the valve when the valve is closed but appears to be partly open, due to the length of time it takes the pipes to empty after being cut off.

Where compactness is a consideration the motor is rigidly attached direct to, or on an extension of, the valve casing. The motor and drive should be so arranged that there will be ample room for hand operation. An enclosed motor is preferred on account of exposure to dampness, water and flooding. Such enclosing is permissible without affecting the size of the motor, owing to the intermittent service. Terminals and wiring also must be protected against water and any mechanical injury which might result while repairs are being made to the valve.

A valve should not be overpowered by a motor for the reason that there is considerable risk of damaging the valve, and should not be underpowered because it increases the chance of failure when the conditions are extraordinary. The correct size of motor for the valve will vary with the duty and the general conditions under which the valve operates. A low pressure steam valve may operate satisfactorily with a two-h.p. motor; whereas the same size hydraulic valve under 100 pounds (45 kg.) pressure may require a ten-h.p. motor to operate it, other things being the same.

Where there is any choice of system the direct current is preferred in order to secure the advantages of a series wound motor, high starting torque and increased speed under light load. The commutator and brush rigging, however, are apt to give trouble in damp or wet locations, from condensation, flooding, long periods of inoperation and lack of attention. The a-c. motor best adapted to valve operation is the squirrel cage type, because of its simplicity. The motor should be designed with a high resistance rotor to increase the starting torque.

For equivalent performance, that is, the same assurance against failure of motor to operate the valves, the a-c. motor should be from 20 to 40 per cent larger than the d-c. motor. In such applications motor efficiency does not enter, but operating efficiency does, and therefore it is economy to put on motors of greater capacity than actually required under ordinary conditions.

For remote control the ideal arrangment is one which permits of automatic starting and stopping of the motor by simply throwing a switch or controller and one that makes it impossible to start the valve in the wrong direction and wreck some part of the valve or mechanism.

Where valves require d-c. motors larger than can be thrown directly across the line without resistance, such resistance should be designed to give the maximum torque required to open the valve and be retained permanently in circuit. As the motor speeds up due to decrease in load, a step of sufficient resistance should be inserted in series with the motor to prevent excessive speed at light load, to slow down the motor as the torque increases near the closing point and to limit the torque finally should the valve seat itself before the motor is disconnected from the circuit.

There are various schemes for obtaining this result with a two-point reversing drum controller or with a pilot switch control in combination with shunt and series wound contactors. In either case, limit switches should be provided at each end of travel. The one at the closing end will require closer adjustment than the other one and the adjustment should be such that the valve will finally seat itself by the drift of the motor.

The scheme of connections for a series motor, shown in Fig. 1, makes use of a drum controller in connection with limit switches carrying the motor current. Fig. 2 is a scheme of control using the pilot switch and limit switches in series with the winding of the contactors. The lock-out relay is inoperative until the motor current drops to any desired value, at which time the lock-out relay opens the shunt circuit of the contactor used for short circuiting the running resistance when starting. This resistance remains in circuit as long as there is any load on the motor.

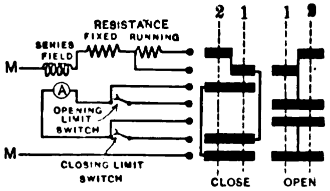

FIG. 1.

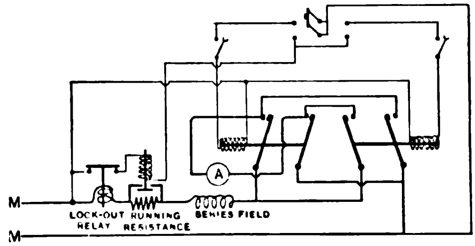

FIG. 2.

For a-c. motors the same general scheme can be used. The a-c. motor will not increase in speed appreciably with change in load but the resistance in the stator circuit will also have the effect of limiting the torque in closing the valve.

The limit switches can be designed to handle the motor current instead of the contactor exciting current. For small valves the limit switch is sometimes omitted and the motor allowed to increase its torque to the point of operating an overload circuit breaker. Such an arrangement, however, is not foolproof, in that it allows the operator to start the gate in the same direction at the end of its travel.

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ADVANTAGES OF AUTOMATIC CONTROL IN STEEL PLANT OPERATION

BY STEWART C. COEY

The problem of motor control in industrial practise and especially in steel plant operation is one in which there is as great a diversity of opinion as in any other problem that presents itself to the industrial engineer. In this paper, it is the intention to take up some of the reasons for the use of automatic control for motors as opposed to manual control, and also some of the tests which have recently been made at the Youngstown Sheet & Tube Co. on the new developments in automatic control which have been brought about by the use of the series-wound accelerating switch, and the deductions and standards that have resulted from these tests, in connection with previous experience in automatic and manual control.

The development of automatic control has been carried on for some time for use on both a-c. and d-c. motors. In steel plant operation, this is confined for the most part to three-phase, 25-cycle, 220-volt induction motors and 220-volt d-c. motors. In alternating-current control the practise has been to use wound rotor induction motors with accelerating switches in the secondary circuit, and reverse switches to reverse two phases of the primary circuit. Within the last year the greatest advance has been in the control of d-c. motors, due, as has been said before, to the advent of the series wound contactor switch for accelerating work. The series switch is in its essential features a switch in which the moving part is so designed that after a certain definite amount of current has been reached in the series coil, the pull on the moving part is reversed due to the saturation of a portion of the magnetic circuit. This fixed locking-out point can be readily changed to suit conditions, and above this point the more the current is increased the greater the locking-out tendency is. After the switch has once closed, any increase in current will only hold it closed more firmly, and the current can drop to about one tenth of the normal full load current of the motor without the switch dropping out.

However, it is not the intention in this paper to take up the question of the design of the series wound contactor switch or any other type of switch. The fact is self-evident that the series contactor eliminates a lot of small auxiliary circuits and butterflies, which are necessary when the shunt wound contactor is used for accelerating, due to the fact that the shunt contactor has to receive its operating current through a butterfly of some kind, which is opened and closed by means of a series coil. In other words, what the series contactor really does is to remove everything from the circuit excepting the series coil, which is necessary in some form when shunt wound accelerating switches are used.

In considering the problem of the use of automatic or manual controllers in steel plant operation one of the most important considerations is found in the fact that a very large proportion of the operators who handle the various controllers are working on a tonnage or piece work basis. These operators are for the most part under the jurisdiction of the various department superintendents, with the possible exception of the crane operators, and in the Youngstown Sheet & Tube Co. even the crane operators come under the department superintendents. It is quite natural that the department superintendents should be more interested in the tonnage output of their departments than in the upkeep of electrical apparatus. The result of this condition is that the various motors are driven to the point of break-down. Now it is an established fact among operating men that no two men will handle a manual controller exactly alike, and the same man will handle it differently at different times, depending on conditions. This results in some men not giving the motors all they will stand safely and others driving them to the limit and beyond. There are very few men who will give the motor just the right amount of accelerating current and even these men will exceed the safe limit without knowing it at times. It is a recognized fact that after a certain amount of output has been obtained from a motor a point is reached where the saturation of the iron, etc., produces a condition where the increased losses in the motor itself represent practically all of the increase in the in-put to the motor. The fact that, by the use of automatic controllers, the point of maximum acceleration can be obtained at each operation without running below at one time and above at another, has the effect of increasing the output of the plant by increasing the average time of doing the work and reducing the number of break-downs on the mill.

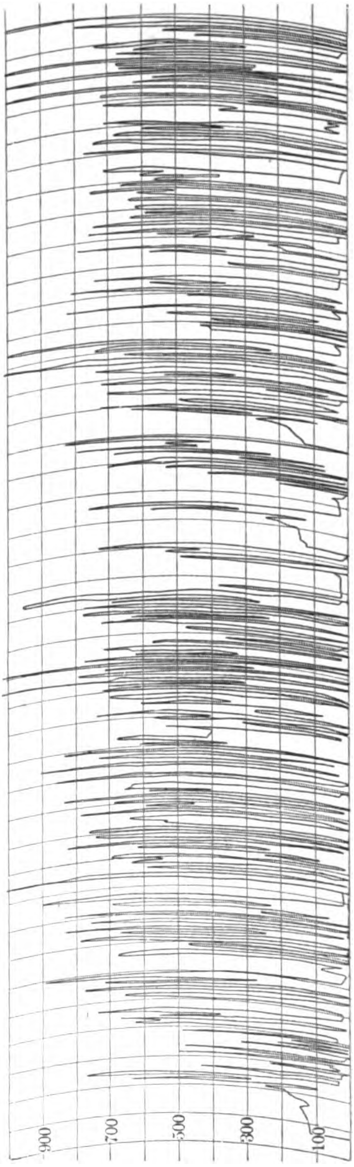
Another factor that causes trouble, when manually operated controllers are used, is found in the fact that one man very often has from three to five or more motors which he has to control simultaneously. In our blooming mill we have for instance a man with the control of two approach tables and a screw-down to take care of. It is absolutely a physical impossibility to use manual controllers in a case like this and get speed out of the mill without plugging the motors. Exactly the same conditions exist on nearly every crane, and more especially on charging cranes. The result of this condition on cranes is that the crane man watches his hoist controller and pays little or no attention to his trolley and bridge control, while on the charging cranes the condition is even worse. It is quite a usual thing to see a bridge controller completely reversed before the bridge motor has lost its motion in the direction from which it is being reversed.

The effect of these various factors on overload protection is really very serious. Whether this protection is obtained by means of some type of circuit breaker or by fuse, the use of manual control results in a condition where the overload protection of the circuit is invariably set at a point greater than the safety of the motor controlled would warrant.

It has been the practise at the Youngstown Sheet & Tube Co. to use automatic controllers on reversing motors larger than 50 h.p. This control has been accomplished by means of shunt wound contactors, with four single-pole contactors for reversing duty, and from three to five of the same type contactors for acceleration.

Within the last year a number of different applications have been made of several makes of automatic controllers with series accelerating switches. These applications have all been successful to a marked degree and have been of great value in determining the type of control apparatus that is being installed in the new mills now under construction.

One of the most interesting applications of the series accelerating switch was on the blooming mill screw-down motor. This motor is a 100-h.p. 220-volt mill motor. The mill has been speeded up until this motor carries an average of about 150 h.p., and in order to keep the armature from throwing the solder out of the commutator necks, a fan blows air through the motor continuously. On December 2, 1911, a controller of the following description was put on this work as a place giving the hardest possible kind of a test. This controller consists of two double-pole shunt switches, for reverse work, five series switches for acceleration, one lockout coil on the third series switch, one single-pole shunt switch as a line circuit breaker, mechanical and electrical interlocks between the reverse switches, and overload coil to open contactor type circuit breaker and reverse switches, and a two-point master controller.



Screw-Down Controller—Final Adjustment. Voltage 220 to 230, 1,000 Amperes Shunt (Youngstown Sheet & Tube Co., December 15, 1911)

The series switches on this board are now set to close at 800 amperes. The current is reversed in the motor on an average 20,000 times a day and on account of the speed necessary in operation, dynamic braking can not be used for stopping the motor with success, and the motor is plugged across the line through its full resistance, which is proportioned for the work. This board has given much better satisfaction than was even hoped for and after a few weeks, operation it was found that the lockout point was unnecessary and it has been taken off entirely since then. The copper tips on the two reverse switches last on an average about six weeks and the cost of replacing these is very slight. There has been very little trouble with the series switches and an entire absence of arcing on them. This installation proves conclusively to our minds the value of the series contactor where speed points are not needed.

The places where speed points are needed require careful thought and study. It is easily seen that tables, transfers and some other motor applications need only one speed, but when we take crane trolleys and bridges it looks at first glance as though speed points were essential. However, by observing carefully it was found that the majority of cranemen seemed to be working only on the last points of their manual controllers and as an experiment a drum reversing switch with a controller consisting of three series switches was put on a 5-h.p. motor on the trolley motion of a 15-ton crane having a 104-ft. (31.6 m.) span. In actual practise it was found that the craneman could "inch" his trolley better with this type of controller than with the old manual type.

These were two of the most interesting points covered by the tests made in the matter of results obtained. Other experiments were made on threading machines with drum reverse and controllers and series accelerating switches. These were very satisfactory, as dynamic braking could be readily used in this case with a great increase in efficiency of operation. The series switch was also found to be of great value in ordinary starting work in place of ordinary hand starters for shears, wet-pans, fans, etc. and has been adopted as a standard in place of hand starters at the Youngstown Sheet & Tube Co.

The main points embodied in the motor control for the new work now being installed at the Youngstown Sheet & Tube Co. are as follows:

All mill controllers are to be automatic. They will have two double-pole shunt switches for reverse duty, either three or four series switches for acceleration, one single-pole shunt switch for line circuit breaker with electrical and mechanical interlocks on the reverse switches, overload coils in both sides of the line arranged to open both the line circuit breaker and the reverse switch, and a reversing master controller.

For crane work, each crane switchboard is to be arranged with a knife switch, a double-pole shunt contactor of sufficient capacity for all the motors on the crane, one overload coil in each of the motor circuits and in the common return, arranged so that if any one trips it will open the double-pole contactor, a safety lock and a reset switch.

The controllers for the trolley and bridge motors are all to be automatic and a duplicate of the mill controllers, with the omission of the overload protection and the single-pole shunt switch for circuit breaker protection.

The controllers for hoisting duty offer the least possible use for the series switch, as it is necessary to use shunt switches to get the speed points on hoisting and the divided power and dynamic braking circuit for lowering. In this type of controller the series switch is used in the same capacity as the series overload coil on the old type of controller.

For sizes less than 15 h.p., the reversing drum has been adopted in place of reverse switches and it is quite possible that the ultimate development along this line will see the reversing drum used in place of the two double-pole shunt switches for considerably larger sizes of motors.

A summation of the results that are obtained in steel plant operation by the use of the automatic controller follows.

1. Reduction in electrical repairs. The use of automatic controllers cuts down the abuse of the motors and hence lessens the number of burnt out armatures, broken shafts, etc. Of course one point must be born in mind in this respect, and that is that unless the automatic controller is made as simple as possible and the ordinary motor inspector can understand it, there is liable to be a loss of time in the end due to the greater length of time that is taken in locating any trouble, which may more than take up the amount of time saved by the reduction in the number of breakdowns.

2. Reduction in mechanical delays. The automatic controller saves all the machinery that receives its power from the motor as well as the motor itself.

3. Increased capacity. The automatic controller allows the motor to work at its maximum efficiency at all times and this in conjunction with the reduction in time lost in breakdowns increases the output of the plant.

A paper presented at the Pittsburgh Meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 25-27, 1912.

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(Subject to final revision for the Transactions.)

DIRECT-CURRENT AND ALTERNATING-CURRENT MILL MOTORS FOR AUXILIARY DRIVES

BY BRENT WILEY

Direct-Current Mill Type Motor

Motor drive for the auxiliary apparatus of steel mills, including tables, screw-downs, cranes, charging machines, etc., has been used for about twenty years. The application of motors to the various machines was naturally a very gradual process. The conditions were very unusual, as the work was of an extremely severe nature, requiring frequent starting and stopping, rapid acceleration and sudden stops. Motors had to operate in very hot and dirty places and in a majority of cases gear drive was used. The mills were operated for 24 hours a day, six days a week. The manually operated direct rheostatic controller was the only type available, and this meant heavy overloads during starting and reversing periods.

These several applications require motors ranging from about 5 h.p. to 150 h.p. on an intermittent rating basis, with speeds ranging from about 800 to 450 rev. per. min. respectively.

Motors for industrial purposes were available only in a few types and these were not very suitable for the severe requirements. The best solution of the problem was to modify the types of series-wound motors used for street railway work, for the sizes above 25 h.p., and the lighter types of motors were used for the smaller sizes. Changes were made in the frames of the railway motors, adding feet and suitable supporting lugs, omitting countershaft brackets for some styles, making windings suitable for 250-volt instead of 550-volt circuits and modifying the full load speeds. There are several hundred thousand horsepower of these motors which have given years of good service in the iron and steel industries, but a careful study of the results showed that the cost of maintenance was high, and for the more severe reversing service the reliability was often questionable. A comparison of the service given by the older types of motors and by the more recent mill type motor will be given later.

About 1905 a very careful review of steel mill requirements was made, in consultation with a majority of the electrical engineers of this industry, to ascertain the features which should be included in a mill type direct-current motor. Many of the electrical engineers of the steel companies keep very accurate records of the service given by the motors installed. The repairs on each motor are kept in detail, in some cases, although the armature repairs are usually the only items compiled by yearly records. These data were of particular value in determining the principal features of improvements to be incorporated in the new motor. Thus, by combining the skill and experience of the manufacturer and the mill engineer, a most satisfactory design of motor has been developed.

The principal features that have been recommended to be included in the design of a motor for mill and similar work are as follows:

1. Motor designed for intermittent service, 220 volts, with series and also compound windings, the latter to give approximately twice full load speed at no load.
2. Sizes ranging from 5 h.p. to 150 h.p. intermittent rating, with moderate speeds.
3. Large massive *steel* frame with well ribbed foot supports.
4. Large shaft.
5. Liberal face and pitch of pinion and gears.
6. Bearings split, bolted together and provided with eye-bolts to facilitate handling of armature.
7. Oil ring lubrication and dust-proof bearings.
8. Improved methods of preventing oil creepage along armature shaft to winding and commutator.
9. Tapered shaft extension, with retaining nut exterior to pinion, to facilitate removal of pinion or brake wheel.
10. Armature built on a spider to facilitate removal of shaft and insure rigid construction.
11. Fire-proof windings (armature and field coils.)
12. More substantial methods of holding armature coils in place, including banding wires sunk below surface of laminations and coil supports at end.
13. More liberal commutator surface.
14. More substantial and better insulated type of brush holders.

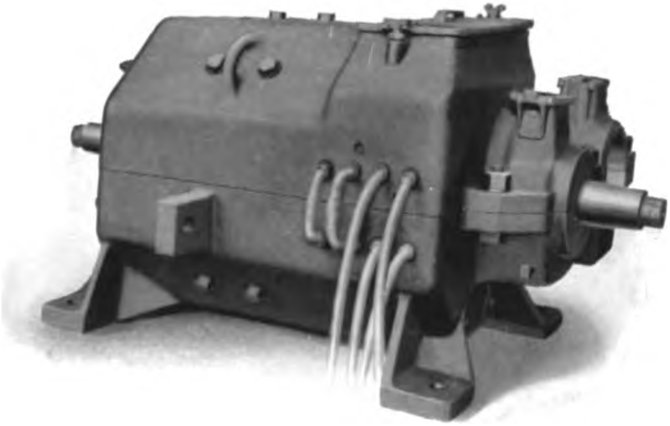

FIG 1.—DIRECT-CURRENT MILL TYPE MOTOR [WILEY]

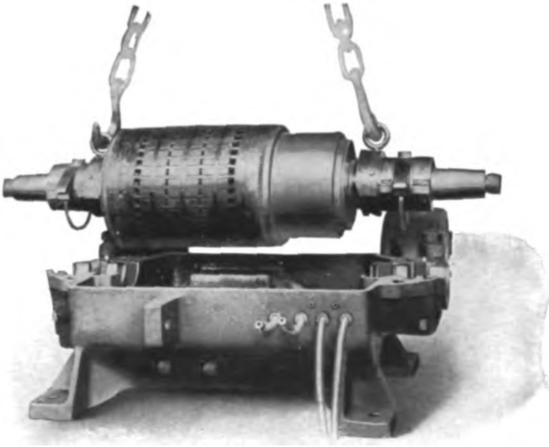

FIG. 2.—REMOVING ARMATURE AND BEARINGS [WILEY]

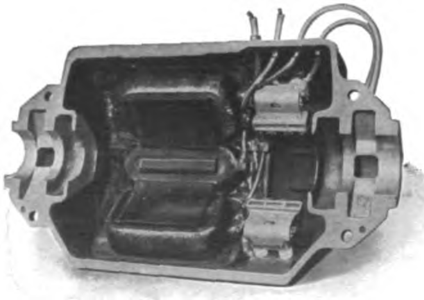

FIG. 3.—UPPER HALF OF FRAME WILEY]

15. More convenient design of frame for inspection and replacement of brushes or brush holders.

16. Commutating pole features which give the following advantages:

    a. Practically perfect commutation under all conditions of load and voltage within the capacity of the motor.

    b. No injurious sparking when the motor starts with very high torque or is momentarily overloaded.

    c. Greatly increased working capacity owing to the increased commutating ability.

    d. Low repair expense and great reliability of operation owing to long life of commutator, brushes and brush holders.

As many parts as possible should be made in duplicate, including armature shaft extensions on each end, bearings, field coils and brush holders. These features simplify the construction and also the maintenance of the motor. These several points can best be amplified by referring to the engineering consideration of the details of design.

The frame should be of cast steel and arranged for ease of inspection of parts, with large openings for the inspection of the commutator and adjustment of the brushes.

The armature should be so designed that the shaft can be removed without disturbing the windings or the commutator. The flywheel effect of the armature should be low to minimize power required for acceleration and reversing.

The insulation of the armature and field coils should be capable of standing high temperature (at least 150 deg. cent.) without undue deterioration, and particular care should be exercised in safeguarding the windings against mechanical injury that might be occasioned by excessive speed of armature and vibration of motor, due to sudden shocks of stopping and reversing.

The commutator should be of liberal design and the current density of the brushes should be approximately one-half that used for the older types of motors, being about 40 amperes per sq. in. (6.45 sq. cm.) for the average motor. Grounding of the commutator at the V-rings has been one of the serious troubles in the older types of motors and particular care should be taken to guard against this collection of grease, oil and dust. It would be well to thoroughly enclose the commutator in the rear, and where oil ring lubrication of the bearing is used, the following suggestions are made to prevent creepage of oil along the shaft to the commutator and windings: oil bearings drilled at the ends to provide drainage back into oil cells; halves of bearing bolted together; splash guard provided around oil ring and oil thrower used on shaft.

It would be an advantage to have split bearings to facilitate their replacement without disturbing pinion or brake wheel; and a projecting lug to prevent turning of the bearing, instead of a dowel pin, would be an improvement. For handling the armature, a permanent eye-bolt in the bearing provides a ready means and is much preferable to the use of a rope sling.

Long life of the bearings is a very desirable characteristic and this is best secured by means of oil ring lubrication. It would be well, however, to have the bearing so designed that grease lubrication can be easily provided for some cases, such as a motor that has to be tilted through a wide angle.

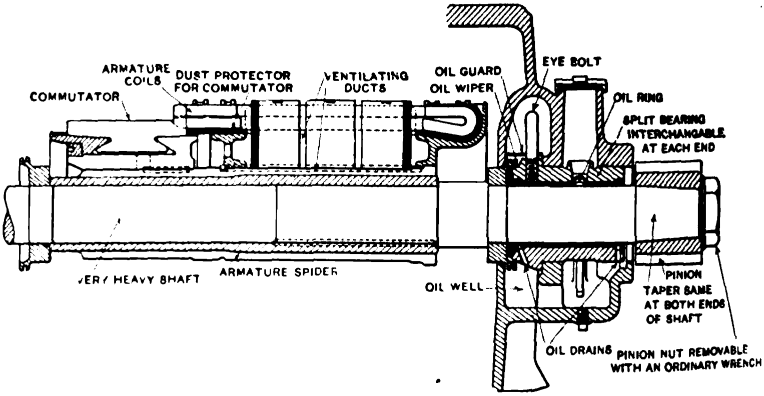
ARMATURE COILS
DUST PROTECTOR FOR COMMUTATOR
VENTILATING DUCTS
OIL GUARD
OIL WIPER
EYE BOLT
COMMUTATOR
OIL RING
SPLIT BEARING INTERCHANGABLE AT EACH END
VERY HEAVY SHAFT
ARMATURE SPIDER
OIL WELL
PINION
TAPER SAME AT BOTH ENDS OF SHAFT
OIL DRAINS
PINION NUT REMOVABLE WITH AN ORDINARY WRENCH

FIG. 4.—SECTIONAL VIEW OF ARMATURE AND BEARING HOUSING

The brush holder should be of rigid design, firmly held in place and well insulated to prevent grounding, as motors are required to operate in places that are dirty, sometimes very hot and often quite damp.

A great deal of attention has been given to the subject of rating for mill motors. The service for which they are used is of an intermittent nature with wide variations of load within short time intervals. As a general basis, the ratings are given as the horse power developed with a maximum temperature rise of 75 deg. cent. in the core and windings and 80 deg. cent. on the commutator for continuous operation at normal voltage for a period of one hour. It would be well, however, to give a table of ratings ranging, say from 5 hours to $\frac{1}{4}$ hour, and as the motor is in actual service only a portion of the time, the ratings should be given at reduced voltage at the motor terminals. The voltage at the motor terminals is practically proportional to the speed during the accelerating and decelerating period, and a very practical way to estimate the average voltage is to plot the speed-time curve of the motor for the particular cycle in question.

To select a motor for intermittent duty, having given the load, the time on and the time off, a very practical method is to estimate the continuous capacity required, by the square root of mean square method.

In the majority of cases, intermittent service means the repetition of a rather definite cycle of operation for several hours. This cycle should be plotted in order to determine the load, the time on and the time off. Take, for example, the hoist of an ore bridge with the following conditions:

Closing bucket	50 h.p.	8 seconds.
Hoisting bucket with load	120 h.p.	10 "
Trolley in	0 h.p.	10 "
Opening bucket	20 h.p.	8 "
Trolley out	0 h.p.	10 "
Lowering bucket with dynamic braking	50 h.p.	9 "
Total cycle		55 seconds.

This cycle to be repeated for a total period of 5 hours.

The two principal factors which are taken into consideration in determining the proper size of motor are commutation and capacity from the standpoint of heating. Making proper allowance for the peak load due to acceleration, the data given above are sufficient to determine the question of commutation, but the heating effect of this varying load is a rather complex problem. It is probably best expressed in terms of an equivalent continuous load, it being noted that the voltage at the motor terminals is reduced in accordance with the speed-time curve as given above.

A practical way of approximating this equivalent continuous load is by means of the square root of mean square method, which is as follows:

Square the load and multiply by the time for each part of the cycle; add the several results; divide by the total time of one cycle, and extract the square root of the quotient. The result is the load which, if applied to the motor at the average voltage, will produce the same heating effect as the varying load. Thus, for the example given above,

$$\begin{array}{rcl} 50^2\times 8 &=& 2{,}000 \\ 120^2\times 10 &=& 144{,}000 \\ 20^2\times 8 &=& 3{,}200 \\ 50^2\times 9 &=& 22{,}500 \\ \hline & 55) & \underline{189{,}700} \\ & & 3{,}450 \quad \sqrt{3{,}450}=59\text{ h.p.} \end{array}$$

It would therefore be a convenient reference to have the motor ratings given for various periods ranging from 15 minutes to 5 hours on the continuous basis, and at reduced voltage at motor terminals, to provide a ready reference, as for example:

5 hr.	........62 h.p.	650	rev.	per	min.	series	wound.
4½ “	.... 63.5 “	640	“	“	“	“	“
4 “	.... 65.5 “	630	“	“	“	“	“
3½ “	.... 68.5 “	618	“	“	“	“	“
3 “	.... 71.5 “	605	“	“	“	“	“
2½ “	.... 76.5 “	577	“	“	“	“	“
2 “	.... 83 “	550	“	“	“	“	“
1½ “	.... 91 “	515	“	“	“	“	“
1 “	.......100 “	475	“	“	“	“	“
½ “	.......150 “	400	“	“	“	“	“
¼ “	.......190 “	360	“	“	“	“	“

Experience shows that in general steel mill work the all-day operation of motors on intermittent service gives a heating effect equal to a continued repetition of the cycle of operation for five hours. This is because of unavoidable delays encountered in actual service. It is therefore usually safe to select the size of motor for all day service on the five hour basis.

Regarding the performance, the mill motor should be capable of standing a heavy overload current, 300 or 400 per cent of full load current, for short intervals, say 5 seconds, without injurious sparking and the momentary safe torque should be at least 100 per cent more than this value. These features increase the working capacity of a motor for some severe applications, as the heating becomes the limiting factor instead of the commutation, and as fire-proof insulation is provided, a safe working temperature is assured much higher than that of the older types of motors. Cotton insulation will stand a temperature of 90 deg. cent. without undue deterioration and

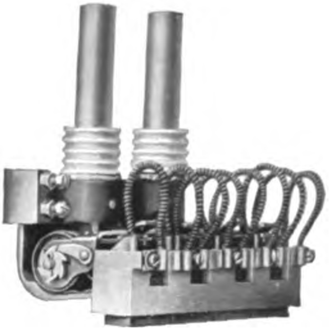
[WILEY]

FIG. 5.—BRUSH HOLDER

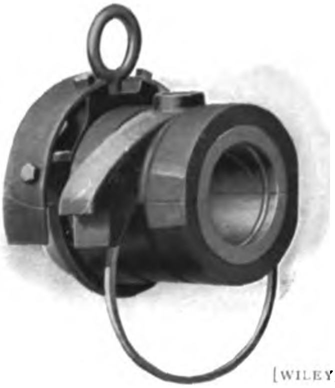
[WILEY]

FIG. 6.—ARMATURE BEARING

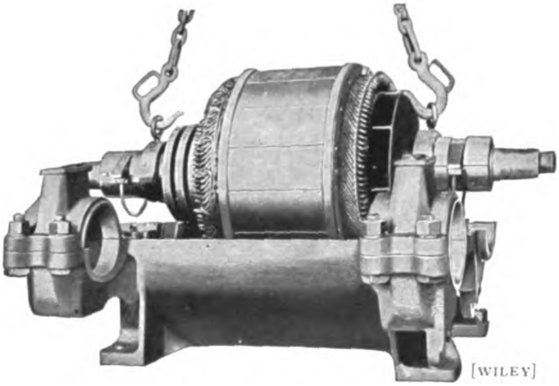
[WILEY]

FIG 10.—LIFTING ROTOR AND STATOR FROM FRAME, A-C. MILL TYPE MOTOR

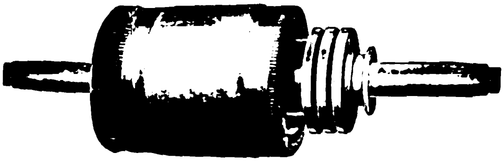
FIG. 11.—ROTOR [WILEY]

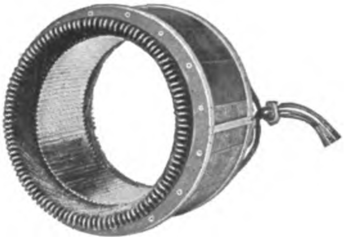
FIG. 12.—STATOR [WILEY]

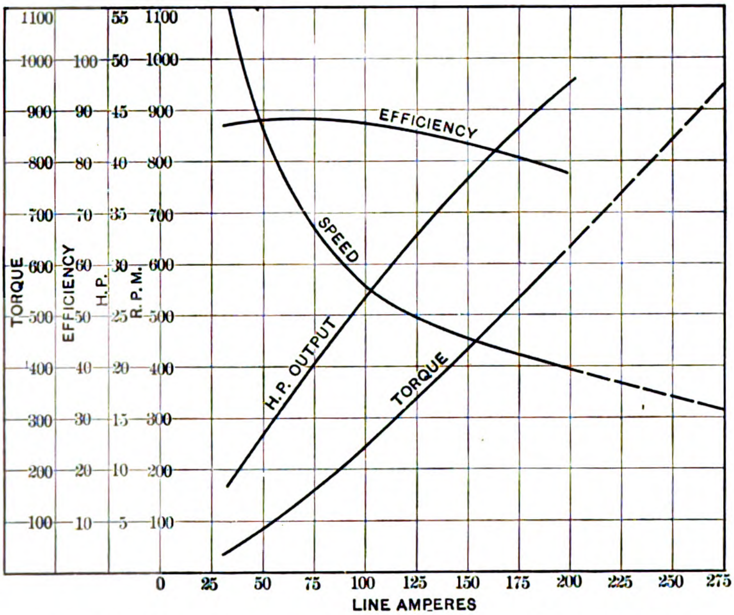

FIG. 7.—CHARACTERISTIC CURVES OF 30-H.P. SERIES WOUND MILL MOTOR

(1 hr.-75 deg. cent. temperature rise. 230 volts)

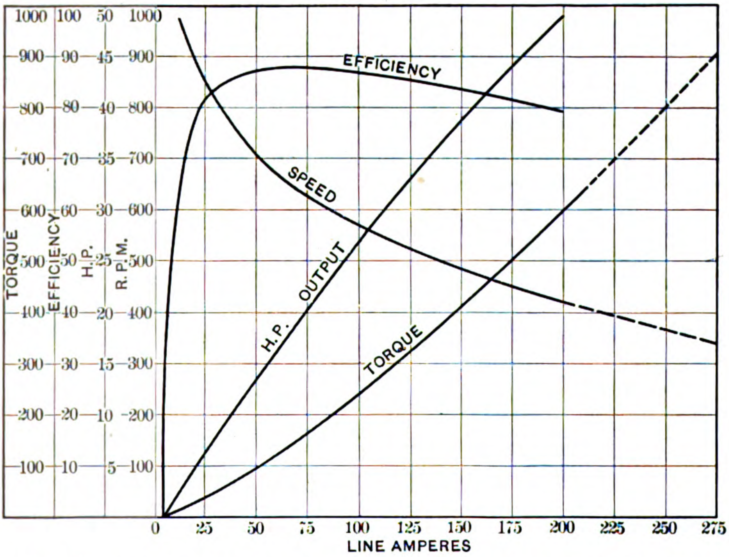

FIG. 8.—CHARACTERISTIC CURVES OF 30-H.P. COMPOUND WOUND MILL MOTOR

(1 hr.-75 deg. cent. temperature rise. 230 volts)

the insulation of mill motor windings should stand 150 deg. cent. safely, which is more than a 60 per cent increase.

The advance in the art of electrical engineering in the steel industry insures a more accurate selection of motor size for the various applications; and the recently developed types of controllers provide special protection against unnecessarily severe conditions being imposed on the motors. While these factors are a distinct advantage, it is the many points of superiority in design which insure the durability and reliability of the mill type motor. Data have been obtained from the records of the electrical departments of several of the large steel companies, relative to the service given by railway crane type, 220-volt, direct-current series motors and mill type motors.

ONE YEAR RECORD OF ARMATURE REPAIRS

	25-h.p. railway crane type.	25-h.p. mill type.	50-h.p. railway crane type.	50-h.p. mill type.
On crane................	742	117	341	17
On floor machinery......	247	68	80	30
Total...............	989	185	421	47
New armature coils (sets).	400	6	306	4
New commutators.......	255	0	181	0
New shafts.............	71	0	30	0

Average plant operation during year, 75 per cent of normal capacity.

It should be noted that the railway crane motors have been in service for more than 10 years and the mill motors less than two years, average, and therefore the figures given above are not on an even comparative basis. Making a liberal allowance, however, for deterioration and wear for the mill type motors, as figured from the records of those in service for the longest period, the comparison of the durability of the two types of motors is as follows:

	Average life of armature.
Railway crane type motors......................	2½ years
Mill type motor................................	10 "

ALTERNATING-CURRENT MILL TYPE MOTOR

The majority of power station improvements of industrial plants have of recent years included alternating-current generators, principally on account of the economy of transmission and wide range of practical sizes of generator units as compared with direct-current power. The steel industries have followed this practise with but few exceptions and, principally on account of slow motor speeds sometimes required, 25 cycles has practically been adopted as a standard. It is both economical and desirable to utilize this power as directly as possible, and alternating-current motors are preferable for the auxiliary drives, except possibly for a small percentage of applications where the work is very severe, requiring very rapid acceleration and frequent reversals. The direct-current series-wound motor has characteristics best suited for these particular requirements, but on analysing steel requirements in general, it will be found that these are few.

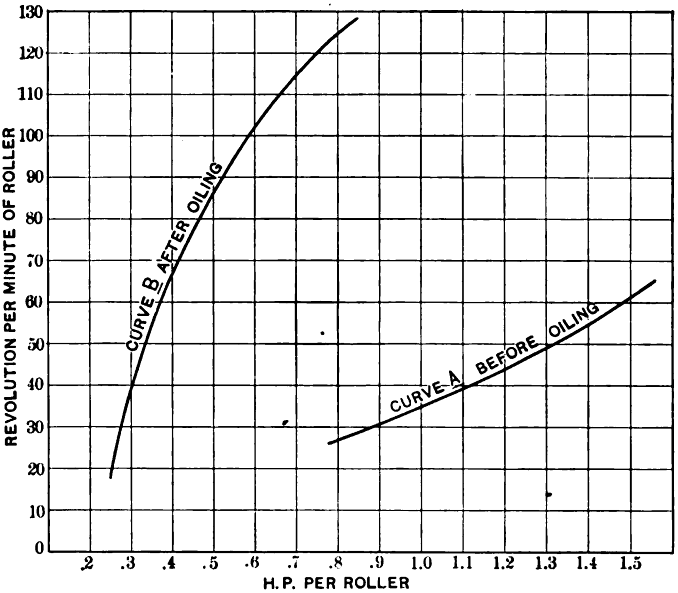

FIG. 9.—MOTOR-DRIVEN ROLLER TABLE

22 Rollers, 1,300 lb. each

The general features of the alternating-current mill motor to meet these severe conditions should be the same as recommended for the direct-current motor, with sizes ranging from about 5 h.p. to 150 h.p. and speeds ranging from 750 to 375 rev. per min. (synchronous).

The frames should be of cast steel and the construction of motor very strong and rigid throughout. The design should be such that all parts are easily accessible for inspection, adjustment and repairs. Reliability and durability should be given particular attention, and it is recommended that fire-proof windings of rigid construction, firmly held in place, large shafts and other features to insure liberal safety factors throughout be included.

The performance should be such that high starting torque is obtained with comparatively low starting current, and the pull-out torque should average about three times full load torque.

In order to obtain the best starting conditions with the alternating-current mill motor, a careful study of the requirements and the motor characteristics is necessary and is a much more important feature than for the direct-current motor. This point can be emphasized best, perhaps, by giving a review of the starting characteristic curves of the alternating-current motor.

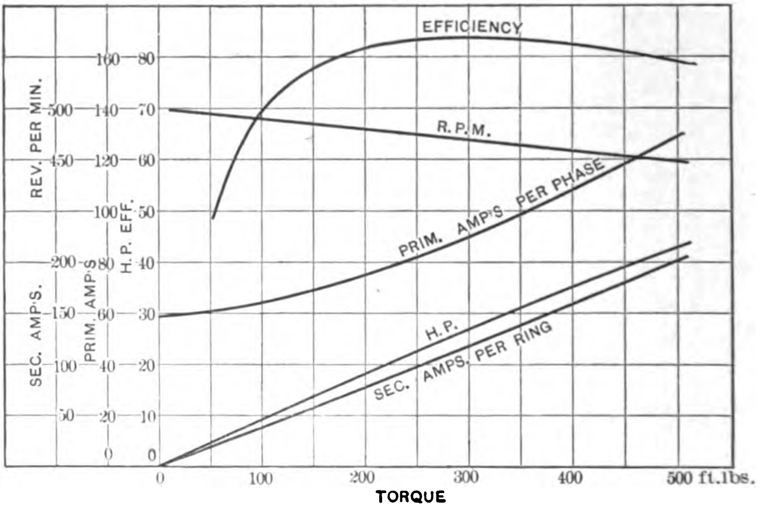

FIG. 13.—CHARACTERISTIC CURVES OF 33-H.P. WOUND ROTOR A-C. MILL MOTOR
(1 hr.-75 deg. cent. temperature rise)

*"In determining the best starting condition, the current supplied to the primary must be considered in connection with the speed-torque curves. This current is plotted with the

---

*Extract from an address on *The Polyphase Motor* by B. G. Lamme, presented at the twentieth convention of the N.E.L.A., 1897.

series of speed-torque curves shown in Fig. 14. Referring to this figure, curve *A* represents the primary amperes in terms of torque. Starting at the point *B* of no load or zero torque, it rises at a nearly uniform rate until maximum torque is approached, that is, below the point of maximum torque the current is nearly proportional to the torque, but beyond this point, the current continues to increase and reaches a maximum at the torque represented by zero speed. At reversed speed, this current is further increased. This one current curve holds true for all the speed-torque curves *a*, *b*, *c*, *d*, etc.

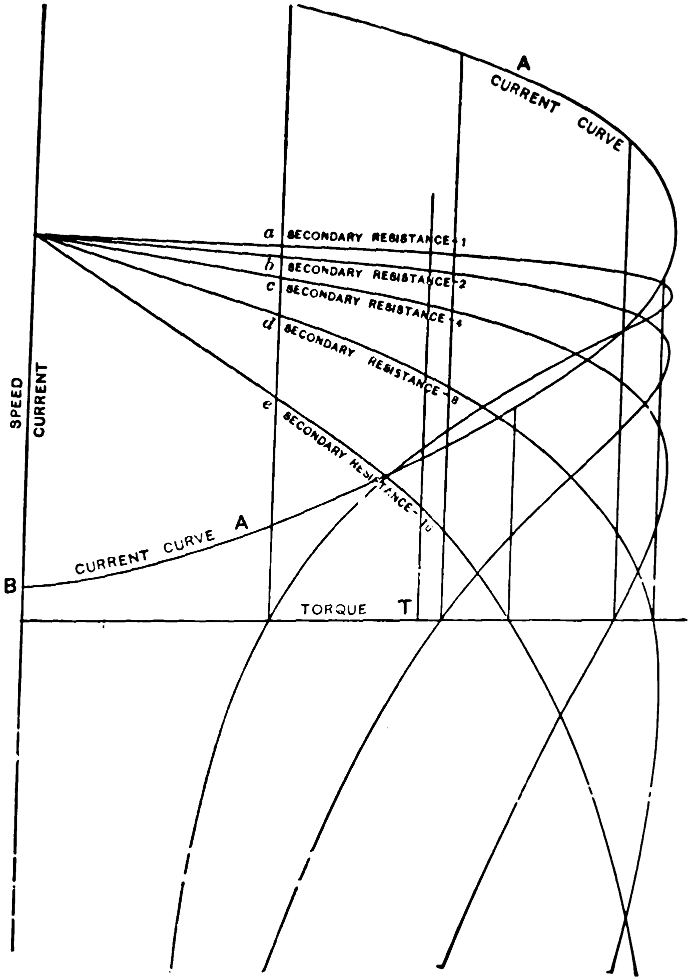

FIG. 14.—FULL SPEED TORQUE AND CURRENT CURVES OF POLYPHASE MOTOR WITH DIFFERENT SECONDARY RESISTANCES

"Comparing the different curves, we see that *a* takes the most current at start, and gives low torque, *b* takes less current than *a*, and gives more torque; *c* takes less current than *b*; *d* takes less current than *c* and gives the maximum torque at start; *e* takes less current than *d*, and develops less torque, but the current and torque are very nearly in proportion over the whole range. From this we see that a speed-torque curve of the form *d* or *e* is decidedly better for starting than *a* or *b*. But for running at less than the maximum torque, there is no advantage, so far as current is concerned, in curve *d* over curve *a*, and the speed regulation of *d* is poor.

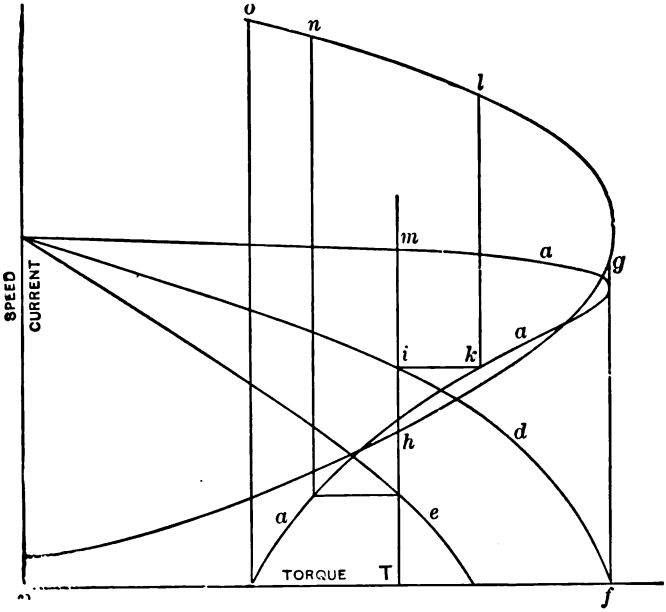

FIG. 15.—STARTING CONDITIONS WITH VARIABLE SECONDARY RESISTANCE

"Fig. 15 represents the condition of speed, current, etc., when a variable secondary resistance is used in starting. The motor starts with torque indicated by *f* on the curve *d* and takes current *g*. The current falls to *h* while the speed rises to *i* which corresponds to the normal torque *T* at which the motor will run under the given conditions as long as it operates on curve *d*, the speed meanwhile remaining at *i*. If the resistance in the secondary is now short circuited, and the load thus shifted to the speed-torque curve *a*, the torque at the speed *i* increases to *k* on the torque curve *a*. The current corresponding to this is *l*; as the torque *k* is greater than the normal torque *T*, the motor will increase until normal torque is reached again at *m*, while the current falls from *l* to *h*.

"At the moment of cutting out the secondary resistance, there was a very considerable increase in the current. By arranging the starting resistance in the secondary, so that the motor will start at some curve intermediate between *a* and *d* and thus take more current at start, somewhat less would be required upon switching to curve *a*. If curve *a* is used for starting, and if the torque required when speeding up is greater than at the point where curves *a* and *e* cross each other, the motor will not pull up, because in switching from *e* to *a* the torque falls, and the motor will stop. The current in switching over increases to *n* and then rises to *o* as the motor stops. In this case, the resistance that gives curve *e* is too great, and a lower starting resistance is required.

"By making several steps in the secondary resistance, so that it can be cut out gradually, the motor can be made to pass through a series of speed-torque curves with much smaller variations of current than shown in the preceding diagram."

It can be stated generally that in the case of the alternating-current motor, the torque is proportional to the current, with properly regulated resistance steps. In starting, the torque of the direct-current series motor is in a somewhat greater proportion—twice full load current giving 2½ times full load torque (see Fig. 7)—and it is not necessary to govern the cutting out of the resistance so accurately to insure a continued high torque. These conditions can, however, be properly provided for in the case of the alternating-current motor. Magnetic controllers can be provided which automatically govern the cutting out of the resistance to the best advantage, and with the hand operated controllers, a little training and care on the part of the operator will give the desired results. These inherent features of the alternating-current motors protect the driven machines from abnormal shocks as well as protecting the motors themselves from mechanical abuse.

The series-wound motor has high speed at light loads, which is a desirable feature for the hoist of a crane motor. As the speed of the alternating-current motor varies but little with change of load a somewhat larger motor is required to give a speed which will be equivalent to the average of the light load and full load speed as given by the proper direct-current motor. For example, if the hook speed is 40 ft. (12 m.) per minute no-load and 20 ft. (6 m.) per minute full load, with the latter motor, an alternating-current motor capable of giving a speed of 30 ft. (9 m.) per minute is required to accomplish a cycle of operation in the same time. In the case of the bridge travel and the trolley travel of the crane, the difference in motor characteristics is not so apparent, as the load is practically constant when up to speed.

Motors designed with liberal starting torque will give satisfactory acceleration.

The proper application of the alternating-current mill motor to give satisfactory service is not only a question of motor characteristics, but more particularly includes a thorough understanding of the conditions to be met, and it is recommended that particular attention be given to the detailed analysis of requirements. With these more definitely established, a more general use of the alternating-current mill motor, with its many attendant advantages, is assured.

A paper presented at the Pittsburgh Meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 25-27, 1912.

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THE OPERATION OF A LARGE ELECTRICALLY DRIVEN REVERSING ROLLING MILL

BY WILFRED SYKES

In a paper before this Institute* the author referred to the investigations that were made in Europe, preliminary to the installation of the first electrically driven reversing rolling mill, and it is interesting to note that somewhat similar experiments and investigations were made in this country, independently, with the same object in view.

About the middle of 1905, it was decided by the Illinois Steel Co. to make inquiries regarding the possibility of installing an electrically driven reversing universal plate mill, and the engineers of that company made some preliminary experiments with a view to determining the power requirements and the probability of the success of such an installation. After sufficient data had been obtained, so that a power curve could be given to the manufacturers of electrical machinery, propositions were invited, and in the spring of 1906 a contract was let for the complete installation. The machines and apparatus were designed in June, 1906, and the complete equipment was delivered by the end of the year, and started in operation at the beginning of 1907.

In the meantime, the first European installation at Hildegradehuetts was started in operation and before the plant of the Illinois Steel Co. was used commercially, a second European plant was started. It is interesting to note, however, that the installation of the Illinois Steel Co. was the second plant of this type to be ready for service. This plant has been in operation for approximately five years, and it is believed that a description of

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**Electrically Driven Reversing Rolling Mills*, PROCEEDINGS, A. I. E. E., June, 1911.

some of the details of the installation and the results obtained, may be of interest.

The Illinois Steel Co. was one of the earliest of the American steel works to utilize the blast furnace gases in gas engines, for supplying power for operating its mills, and the principal reason that led to the installation of this pioneer mill was the realization of the necessity for greater economy in the generation and distribution of power in such works.

The characteristics of the universal plate mill are such that it is necessary to have the greatest flexibility possible in the driving machine, and it was realized that by installing an electric motor, controlled by regulating the field of a special generator supplying it with power, an ideal system would be obtained enabling all classes of work to be handled in the most desirable manner, the earlier passes being handled at low speeds and the finishing passes at high speeds, it being possible to obtain the maximum output of the mill on account of the flexibility of the speed control.

When the plant was installed, some doubt was felt as to the possibility of quick reversing, but in operation it was soon found that the electric plant was capable of handling material more quickly than similar steam driven mills and more quickly than the material can be handled by the tables. After the plant had run for some time it was demonstrated that the electric equipment was not the weakest link in the chain. The following brief description of the mill and electrical apparatus will show, to some extent, the nature of the problem involved in the electrification and the methods adopted to insure successful operation.

MILL

The mill is of the two-high universal type, designed for rolling plates up to 30 in. (76 cm.) wide from slabs up to a maximum of 10 in. (25 cm.) thick. The main horizontal rolls are 24 in. (60 cm.) in diameter, and have a face of 34 in. (85 cm.). The vertical rolls, of which there are four, two on either side of the main rolls, are 14 in. (34.6 cm.) in diameter and have a face of 13 in. (32.8 cm.) The mill was designed to roll plates of all thicknesses and, on account of its flexibility, is used to a very great extent for handling small orders. The general layout of the mill is shown in Fig. 1, from which it will be seen that the motor-generator set, for supplying power to the main roll motors, is erected in the same room as the main roll motors. Apart from

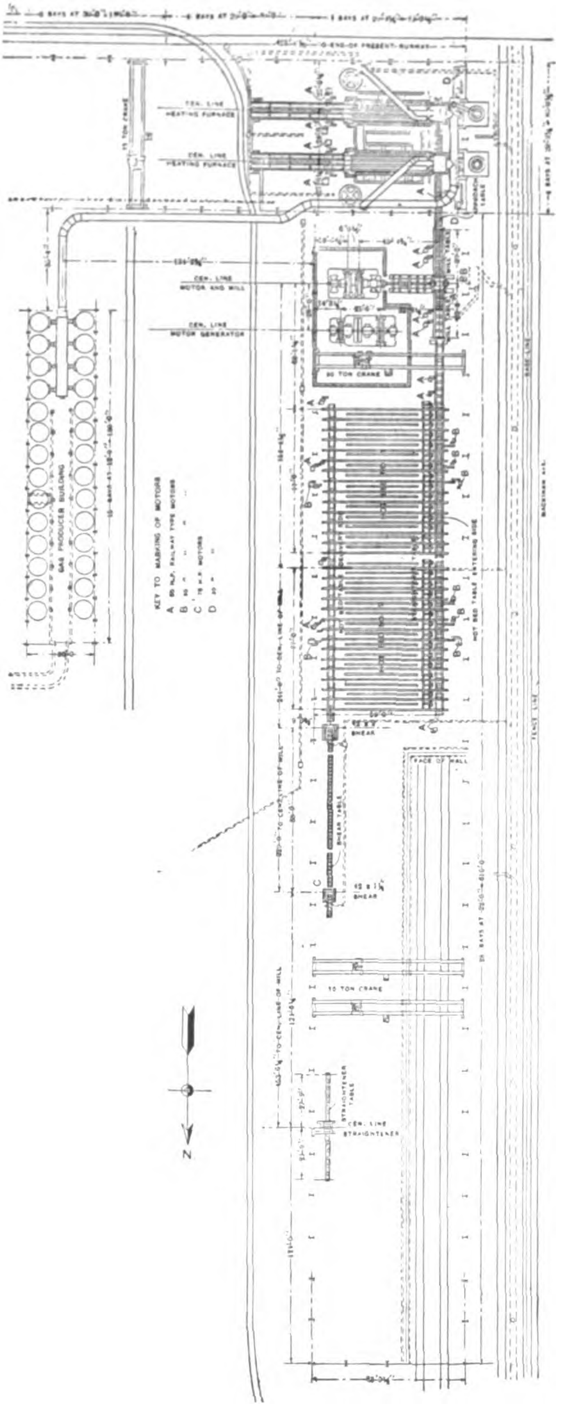


FIG. 1.—GENERAL LAYOUT OF UNIVERSAL PLATE MILL AT THE ILLINOIS STEEL COMPANY'S PLANT.

the method of driving, the mill is not appreciably different from similar steam-driven installations.

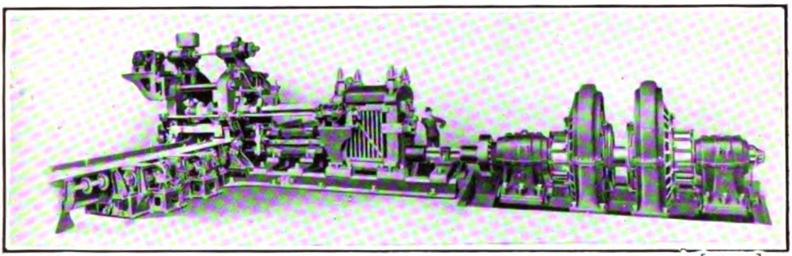
From the general layout drawing, it will be seen that the slabs are heated in two furnaces and carried by an approach table to the mill. When rolled, the plates are taken in two hot beds, and after cooling, to a shearing table, where they are cut to size and are then ready for straightening and shipment. The mill tables are operated by four 50 h.p. mill-motors, the control being located at one side of the mill, close to the control for the main motors. The mill and the motor room are spanned by a 30-ton crane, which is capable of handling all parts of the equipment, with the exception of the flywheels of the motor-generator set.

In Fig. 2 a general view of the mill and motors is given, which shows the appearance of the complete equipment. The motors are enclosed in a separate room to protect them from the mill dust. In this view, the mill is shown complete with motor, but from Fig. 1 it will be seen that there is a wall between the pinion housings and the motors. In the illustration the auxiliary motors for the setting of the rolls are shown, that for the horizontal rolls being mounted to the left of the mill housings and that for the vertical rolls to the left of the pinion housings.

The setting of the horizontal rolls is varied by means of an electrically driven screw-down, the screws being operated by a 50-h.p. mill type motor. The setting of the vertical rolls is controlled by means of a 30-h.p. mill type motor, the position of the rolls being shown by the usual micrometer type of indicators. The main rolls are connected to the pinion housing by suitable spindles, arranged to allow a movement of about 12 in. (30 cm.). The lower pinion is driven from the roll motor through a coupling of the usual mill type, arranged to allow for considerable wear in the pinion shaft bearings. No flexibility is allowed for in the drive from the motor to pinions.

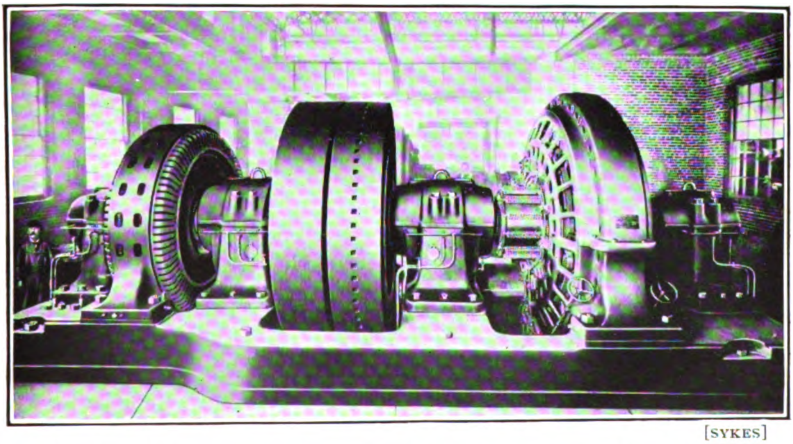
The mill was designed for a maximum speed of 150 rev. per min. but it has been found in practice that about 100 rev. per. min. is all that can be conveniently used, on account of the comparatively short plates rolled.

The capacity of the mill varies considerably on account of the material rolled, and depends more on the product required than on its capacity for rolling, and therefore definite figures cannot be given for the output for any particular product. In referring to some of the tests given, an idea of the capacity under various conditions may be obtained. The performance of a mill of this type



[SYKES]

FIG. 2.—UNIVERSAL PLATE MILL AT THE ILLINOIS STEEL COMPANY'S PLANT, SHOWING THE MOTOR DRIVE



[SYKES]

FIG. 13.—MOTOR-GENERATOR SET INSTALLED IN THE PLANT OF THE ILLINOIS STEEL COMPANY

cannot be compared with that of a blooming mill, rolling practically one size of material. The equipment of this mill had to be sufficiently large to handle the heaviest slabs that can be rolled, although the work is comparatively light most of the time and consequently the tonnage suffers.

System of Driving

In deciding upon the system to be used for driving the mill, and the control of the motors, the experience that had been gained in the design of large hoisting plants of the Ilgner type was drawn upon. In 1903 experiments had been made to determine the possibility of rapid reversing and the sensitiveness of this system of control, on a large hoisting plant. The results obtained indicated that, from the standpoint of control, this system gave all that could be desired, providing the proper provision was made to obtain a rapid change in the generator field. The ordinary solid field generator cannot follow rapid change in the excitation on account of the eddy currents which are set up and which oppose any change of field strength. It is therefore necessary to design the machine with a completely laminated magnetic circuit so as to overcome this characteristic of the ordinary generator when working under the conditions met with in such service. The importance of having the voltage of the generator follow the changes of excitation quickly is very great from an operating standpoint and this condition has been very well fulfilled in the Illinois Steel Co.'s installation.

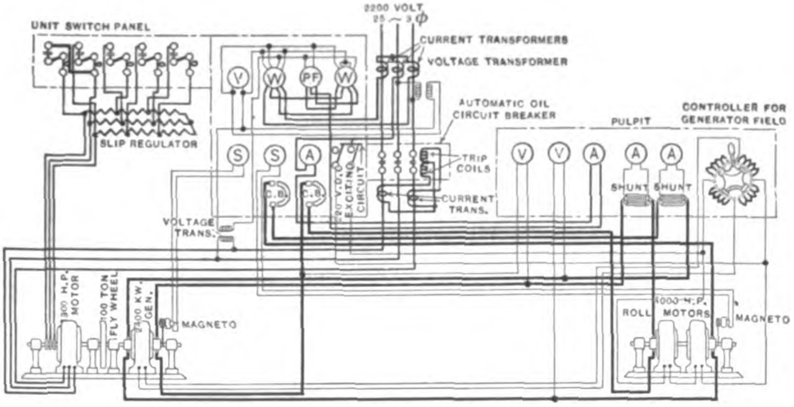


FIG. 3.—DIAGRAM OF CONNECTIONS OF ELECTRICAL EQUIPMENT FOR UNIVERSAL REVERSING PLATE MILL OF ILLINOIS STEEL CO., SOUTH CHICAGO.

In Fig. 3 are shown the principal connections of this installation. It will be seen from this diagram that the roll motors are connected to a double-commutator generator without any starting resistance, each motor being connected to one commutator. This generator is driven by means of a three-phase induction motor, and a 100-ton flywheel is mounted on the same shaft. The roll motors are separately excited, the excitation being constant, with speeds up to 100 rev. per min., and the polarity is not changed. The direction of rotation and speed of the roll motors is controlled by changing the polarity of the generator, and varying its field strength, thereby varying the voltage applied to the armatures of the roll motors. This system avoids rheostatic losses, except in the field circuit, and enables any desired speed to be obtained, independent of the load.

The load on the generator naturally varies rapidly over a large range, the rate of change being at times 3,000 to 4,000 h.p. per second during acceleration and 8,000 to 10,000 h.p. per second when braking. From the standpoint of the power supply, such a load would be highly undesirable, even for a very large power house, and could not be handled at all by gas engine driven stations of moderate capacity, such as usually found in steel mills. In order to equalize these fluctuations, the flywheel was provided to deliver energy during the periods of great demand and to store energy during periods of light load, and so that the flywheel may give up some of the energy stored in it, the speed must be reduced, and to store energy the speed must be increased.

To enable the flywheel to assist the three-phase motor in driving the generator, an automatic slip regulator was provided, which introduces resistance into the rotor when the current reaches a certain value, the speed being thereby reduced, and a portion of the energy stored in the flywheel is used for driving the generator. When the load on the generator is reduced, the resistance is automatically cut out, the speed consequently increasing and energy is thereby stored in the flywheel. In practise, the maximum load on the line due to the reversing set is approximately one-fifth of the maximum load of the generator. By properly setting the regulator in relation to the work to be done, the input to the motor-generator can be maintained practically constant. It will be noted that the driving motor of the set is considerably smaller than the generator, which is due to the fact that the latter must be designed to carry the high peak loads and as the heating of the armature is due principally to the copper loss, which varies as the square of the current, a much greater capacity is required to deliver a certain amount of power than would be necessary if the load were constant. The load on the induction motor does not vary greatly and consequently it is designed to carry only the average load.

To protect the generator and driving motor against excessive overloads, due to stickers or cold slabs, overload trips for the circuit breakers are provided in each armature circuit, which are arranged to open the circuit at a load corresponding to, approximately, 8,000 h.p. The primary circuit of the induction motor

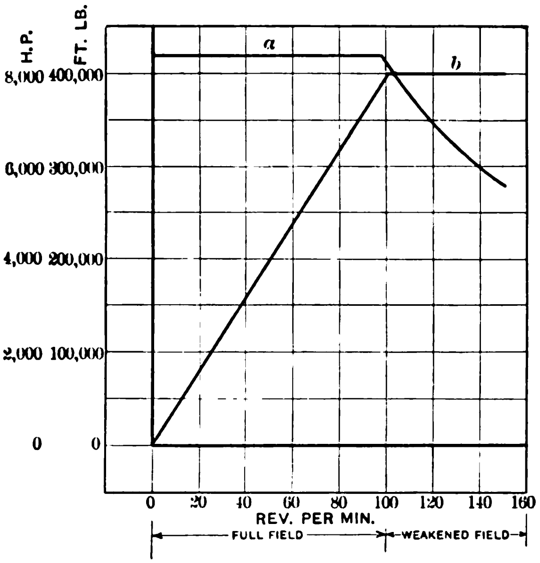


Fig. 4.—Combined Rating of Roll Motors under Maximum Operating Conditions.

a.—Torque. *b*.—Horse Power.

is provided with the usual instruments and overload protection. Speed meters showing the speed of the rolls, and double reading ammeters are provided on the operating pulpit, for the guidance of the operator. It has been found however that the electrical equipment is capable of performing heavier work than the mill so that the operators are controlled during rolling more by the limitations of the mill than those of the electrical equipment.

Driving Motors

The driving motors have a nominal rating of 2,000 h.p. each. making a total of 4,000 h.p. for the set. The maximum combined rating of the motors is shown in Fig. 4, which shows a maximum torque of 420,000 ft-lb. (58,086 kg-m.) at a speed up to 100 rev. per min., which is obtained with full voltage on the armatures. At speeds above this the horse power remains constant, the torque decreasing correspondingly, the higher speeds being obtained by weakening the field of the motors.

The motor was divided into two units, with the object of reducing the armature diameter, and consequently the inertia, and at the same time to facilitate handling the heavy current which at 8,000 h.p. is about 11,000 amperes. They are designed for a normal armature voltage of 575, and 220 volts excitation.

When the plant was designed, it was proposed to increase the speed from 100 rev. per min. to 150 rev. per min. for the longer passes, and, so as to insure that the flux in the motor fields would follow the quick changes of the exciting current, the magnetic circuit was laminated. Experience gained from the operation of the plant has shown that this refinement was unnecessary although required in order to meet the original guarantees for acceleration and reversal asked for.

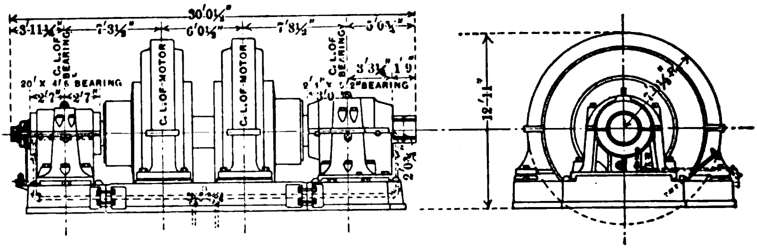


Fig. 5.—Outline of Motors for Driving Mill.

The general dimensions of the machines are shown in Fig. 5, from which it will be seen that the two armatures are mounted on one shaft, supported by two bearings, the field frames being mounted side by side on the bedplate. The laminations are supported by a cast iron frame which is split horizontally to facilitate repairs. The machines are of the commutating pole, compensated type, the compensating windings being imbedded in the face of the main poles. The armatures, which are 7 ft. 6 in. (2.28 m.) in diameter, were especially constructed to stand the severe shocks anticipated with this class of work and to be capable of withstanding the severe stresses due to the rapid reversing and acceleration. On this account, very great attention was paid to the methods of supporting and holding the armature windings, a special steel ring being provided to support and fasten the end connections rigidly where they connect to the commutator lugs. With the ordinary construction, a certain amount of movement is always possible and a very slight bending of the end connectors if repeated often enough will lead to crystallization and breaking, which has been demonstrated repeatedly where machines have been subjected to severe service. That the great care in supporting the end connections was justified, has been demonstrated by the fact that in some of the earlier European installations there was considerable trouble due to the breakage of the armature connections, whereas in the case of this plant there has never been the slightest difficulty from this cause.

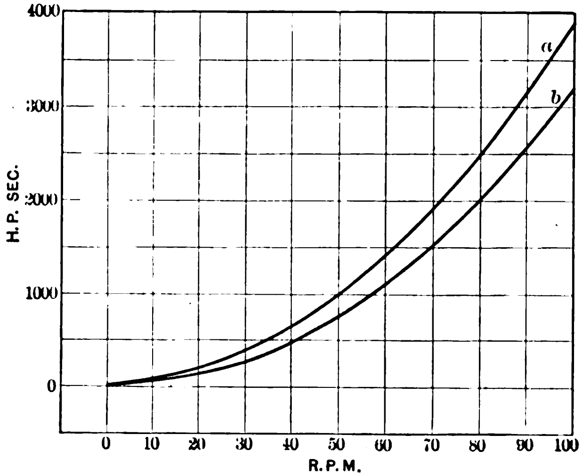


FIG. 6.—CURVE SHOWING ENERGY STORED IN ROTATING PARTS OF ROLL MOTOR AND MILL.
a.—European Installation. *b.*—Illinois Steel Co's. Installation.

The importance of reducing the armature diameter and weight will be appreciated on referring to Fig. 6, which shows the energy stored in the rotating parts of these motors at various speeds, the energy varying as the square of the speed. The inertia curve of a European installation is also shown, the rating of the two plants being almost identical. From these curves it will be seen that in the American installation the inertia has been kept somewhat lower than in the European plant, although the latter was installed about two years later.

Although very high efficiency in the motors of such an installation is not of very great importance, considering the other losses, yet it is desirable, inasmuch as it affects the heating of the machines, and a well designed machine will naturally have high efficiency. In Fig. 7 is shown the efficiency curve of these motors, from which it will be seen that the losses are extremely small. Of particular importance are the copper losses, which control to some extent the energy returned from the motors during braking, as the current is usually high and the period short. It will be noted that the bearing at the coupling end is unusually large and at the maximum load the stress in the shaft is less than 3,000 lb. (1,360 kg.) per sq. in. (6.45 cm.).

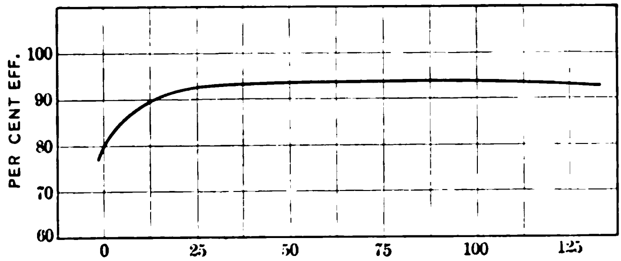


FIG. 7.—EFFICIENCY CURVE OF ROLL MOTORS.
Two 2,000-h.p. Shunt Motors—575 Volts, 2,800 Amperes, 12-Pole, 0-150 rev. per min.
Efficiency at 100 rev. per min., Including Excitation.

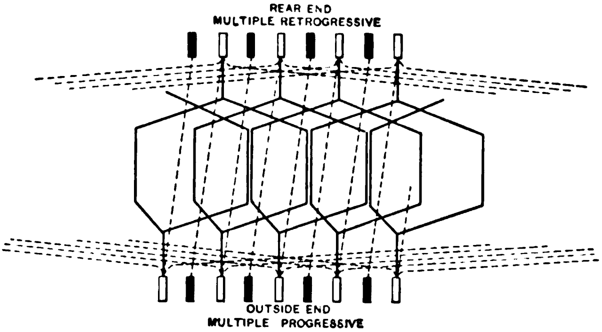


FIG. 8.—ARMATURE CONNECTIONS OF DOUBLE COMMUTATOR GENERATOR SUPPLYING POWER TO ROLL MOTORS.

The weight of the complete motor (two machines) is 356,000 lb. (161,488 kg.) made up as follows:

Rotating part...........	124,000 lb.	(56,245 kg.).
Fields....................	107,000 "	(48,534 ").
Base and bearings........	125,000 "	(56,699 ").

Motor-Generator Set

The generator of this set is of the double-commutator type, and embodies some design features of special interest.

It was decided to use a double-commutator type machine, so as to reduce the current to be collected from a single commutator, thereby allowing a single comparatively high-speed machine to be used. The field is of the laminated type, so built that it will answer changes of field current very rapidly, this being necessary to obtain quick reversing and speed changes.

The machine is of the commutating pole compensated type, similar to the roll motors, the diameter of the armature being the same. The normal full speed of the generator is about 375 rev. per min. and the minimum speed about 300 rev. per min. At 375 rev. per min., the voltage of the generator with full field is, approximately, 600.

The armature winding is of especial interest, as there are twice as many commutator bars as there are coils, the equivalent of a half turn coil being obtained by the connections, as illustrated in Fig. 8.

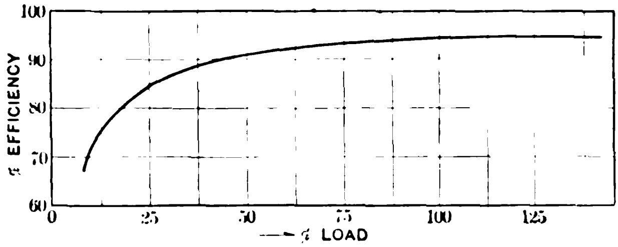


Fig. 9.—Efficiency Curve of Generator Supplying Power to Roll Motors.
Shunt Generator, 3,000-kw. Efficiency at 300 rev. per min., Including Excitation.

The generator is designed for a normal capacity of approximately 3,000 kw. and a maximum capacity of about 6,400 kw. Special attention was given to the design of the generator, to insure good commutation under the severe conditions of operation. The commutating pole and compensating windings are not shunted, care being taken to render this unnecessary, so as to avoid any trouble due to difference in the self-induction of the windings and shunt affecting the division of the current with rapid changes of load. The necessity of commutating the maximum current with a weak field, requires that the closest attention be given to commutating characteristics of the generator.

The efficiency of the machine is shown in Fig. 9, this curve being based on tests made after the plant was installed.

The motor for driving the generator and flywheel has a normal rating of 1,300 h.p., and is designed for three-phase, 25 cycles, 6,600 volts, eight poles. It is of the wound rotor type, the rotor circuit being controlled by an automatic slip regulator, previously referred to, and is of the usual standard construction.

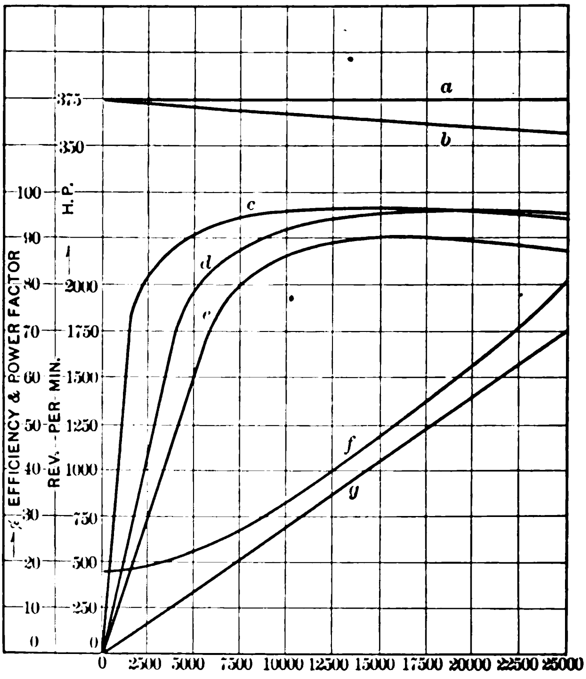


Fig. 10.—Performance Curves of Three-Phase Motor Driving Flywheel Motor-Generator Set.

(1,300 h.p., 2,200 volts, 25 cycles, 8 poles, 375 rev. per min. synchronous speed.) *a*—Synchronous Speed. *b*—Motor Speed. *c*—Real Efficiency. *d*—Power Factor. *e*—Apparent Efficiency. *f*—Apparent h.p. *g*—Real h.p.

The performance of this motor is shown in Fig. 10 and the speed-torque characteristics for the various steps of the regulator are shown in Fig. 11.

The flywheel of this set presents some interesting features, as, owing to difficulties in transportation and in obtaining reliable steel castings, the wheel was built of comparatively thin punched laminations on a steel spider, the sheets being bolted between cast steel end rings. The peripheral speed of the wheel at 375 rev. per min. is 15,500 ft. (4,724 m.) per minute. In order to facilitate handling, the wheel was built in two parts, each weighing 100,000 lb. (45,359 kg.), the total weight therefore, being 100 tons. The flywheel effect of this wheel is 5,500,000 ft-lb., and under normal conditions of operation, the speed of the set seldom falls below 320 rev. per min., and the input does not as a rule exceed about 900 kw. The energy stored in the wheel at full speed is 250,000 h.p-sec., and the amount given up when the wheel slows down to 300 rev. per min. is 90,000 h.p-sec.

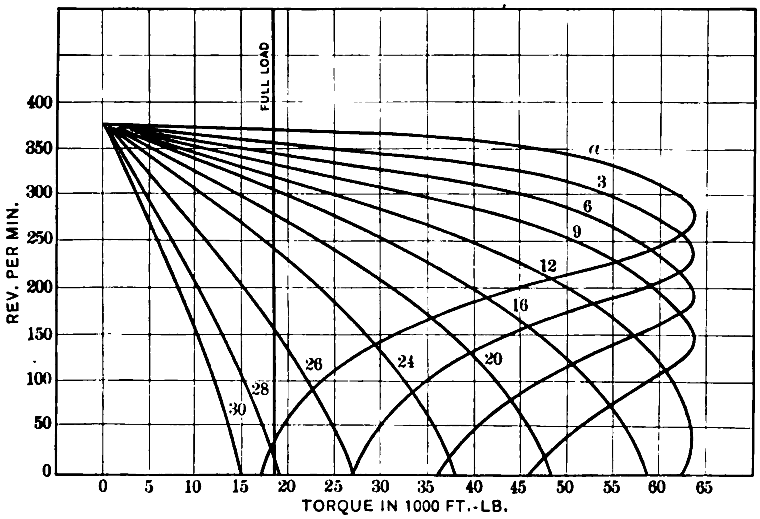


FIG. 11.—SPEED-TORQUE CURVES OF THREE-PHASE MOTOR FOR DIFFERENT STEPS OF SLIP REGULATOR.

(1,300 h.p., 2,200 volts, 25 cycles, 8 poles, 375 rev. per min. synchronous speed.)

Curve *a*—Rotor Ring Short-Circuited. Curves *a*-3-24—Running. Curves 24-30—Starting.

The general assembly of this set is shown in Fig. 12, which gives the principal dimensions, and a view of the complete machine is shown in Fig. 13. The rotating parts are supported by four bearings, the flywheel having a bearing on either side and a separate shaft. The shafts for the motor and generator are supported at one end by a bearing, and at the other are bolted to the flywheel shaft. The maximum bearing pressure has been limited to approximately 80 lb. (36 kg.) per square in. (6.45 sq. cm.). Both machines and the flywheel are mounted upon a single base plate, which is securely fastened to the foundation by numerous bolts. All bearings are water cooled and oiled from a central gravity oil system, so as to insure a continuous supply of oil to all wearing parts. In order to facilitate starting the set, a pneumatic barring gear is provided, controlled by a hand-operated triple valve.

CONTROL APPARATUS

For controlling the excitation of the generator, a special controller, operated on the principle of a Wheatstone bridge, was designed, the connections of this controller being shown in Fig. 3. The current handled by this controller is, approximately, 50 amperes, with maximum excitation, which can be readily handled by a controller of the face plate type. The slip regulator for automatically varying the rotor resistance, so as to limit the input, consists of a number of pneumatically operated switches, arranged in groups, their operation being controlled by two relays. One of these relays causes the switches to drop out when the current in the primary of the motor reaches a certain value, and so long as this relay is open the switches will continue to drop out successively. When the current reaches a normal value, the relay closes and no further switches are opened. When the current falls below the normal, the second relay drops, and causes the switches to automatically close in the proper order, and in this way the input to the motor, under normal operating conditions, is maintained approximately constant.

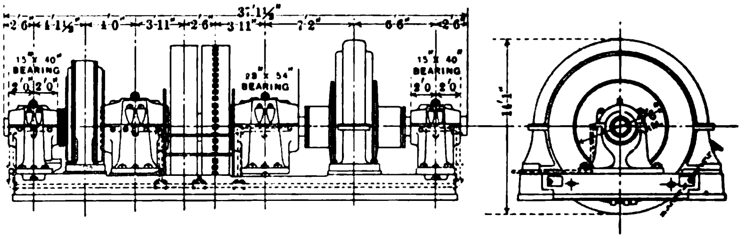


FIG. 12.—OUTLINE OF FLYWHEEL MOTOR-GENERATOR SET SUPPLYING POWER TO ROLL MOTORS.

The connections of this regulator are shown in Fig. 14, and in Fig. 15 is shown a group of the pneumatic switches, which are of the same type as used for the control of large electric cars and locomotives. In all, thirty switches were provided for starting and regulating the speed of the motor, and, consequently, the resistance is varied in very small steps. The capacity of these switches to withstand very severe service has enabled them to be operated successfully since the plant was installed, although each switch may be closed or opened eight or ten times a minute.

TEST RESULTS

After five years' operation of the plant, it was decided that it would be advisable to make a complete set of tests, to de-determine, not only its operating characteristics, but also

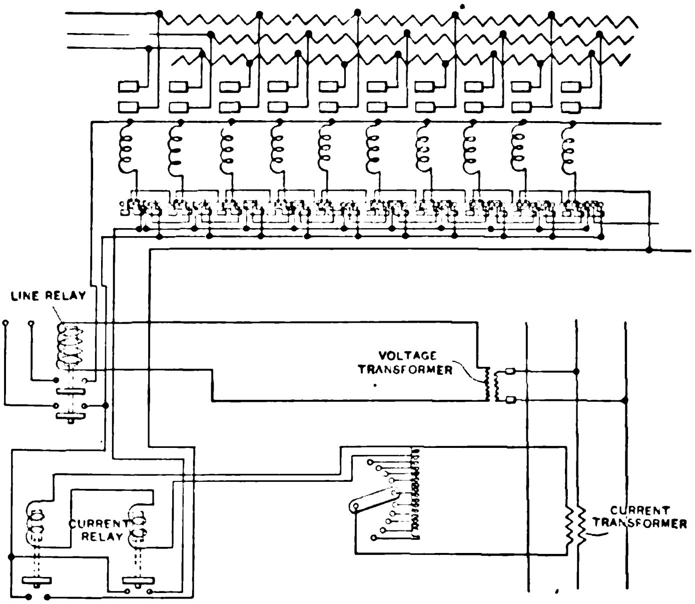


FIG. 14.—DIAGRAM OF CONNECTIONS OF AUTOMATIC SLIP REGULATOR CONTROLLING INPUT TO FLYWHEEL MOTOR-GENERATOR SET.

whether such an installation could be improved upon and how closely the designed capacity approximated to the actual operating conditions. Owing to the difficulty in obtaining suitable apparatus to make such tests, most of the instruments were specially designed and built for this test. The current in the motors varies, under normal conditions, so rapidly that ordinary indicating or recording instruments were not suitable and it was therefore decided to use an oscillograph for recording the direct-current voltage and current. The speed of the roll motors was recorded by means of a special graphic recording meter, controlled by a suitable magneto, driven from the motor shaft. The recording instrument was especially designed so as to be capable of following rapid changes in speed, and to avoid errors usual with graphic instruments. It was decided to avoid the use of a pen for recording and the position of the pointer was recorded by causing a spark to pass from the end of the pointer through the paper to an insulated plate. In designing these instruments, provision was made to avoid introducing errors in the readings due to the static effect of the high-tension current for the spark. The speed recording instrument for the roll motors had a center zero so as to record both directions of rotation.

The speed of the motor-generator set was also recorded, to determine the amount of energy given up or absorbed by the flywheel, during the period of test. The instrument used was similar to that adopted for the recording of the motor speed, except that provision was not made for recording the speed in both directions. In order to obtain a large reading for a comparatively small change of speed, a battery was connected to oppose the magneto, and the meter recorded the difference in the potential of the magneto and the battery. All the instruments, including the oscillograph and the speed meters, were provided with a time recording device, all of these attachments being controlled by a single contact-making clock.

The input of the motor-generator set was determined by means of a wattmeter of the same type as the speed meters.

In addition to the above apparatus, provision was made for recording signals from the mill. In the mill, records were obtained as to the size and weight of material rolled and the reduction per pass, and at the same time readings were taken to determine the temperature of the metal.

These tests gave, simultaneously, readings of the input to the roll motors and the input to the motor-generator set at the speed of the set and motors.

With this information, together with the known characteristics of the apparatus, and the data obtained as to the work done by the mill, it was possible to obtain a complete analysis of the power requirements and operating characteristics.

While it is not possible within the scope of this paper to go into detail as to these tests, a few characteristic curves are given which may be of interest.

Fig. 16 shows the power required for rolling a slab, 3½ by

PLATE XXXVI
A. I. E. E.
VOL. XXXI, NO. 5

[SYKES]

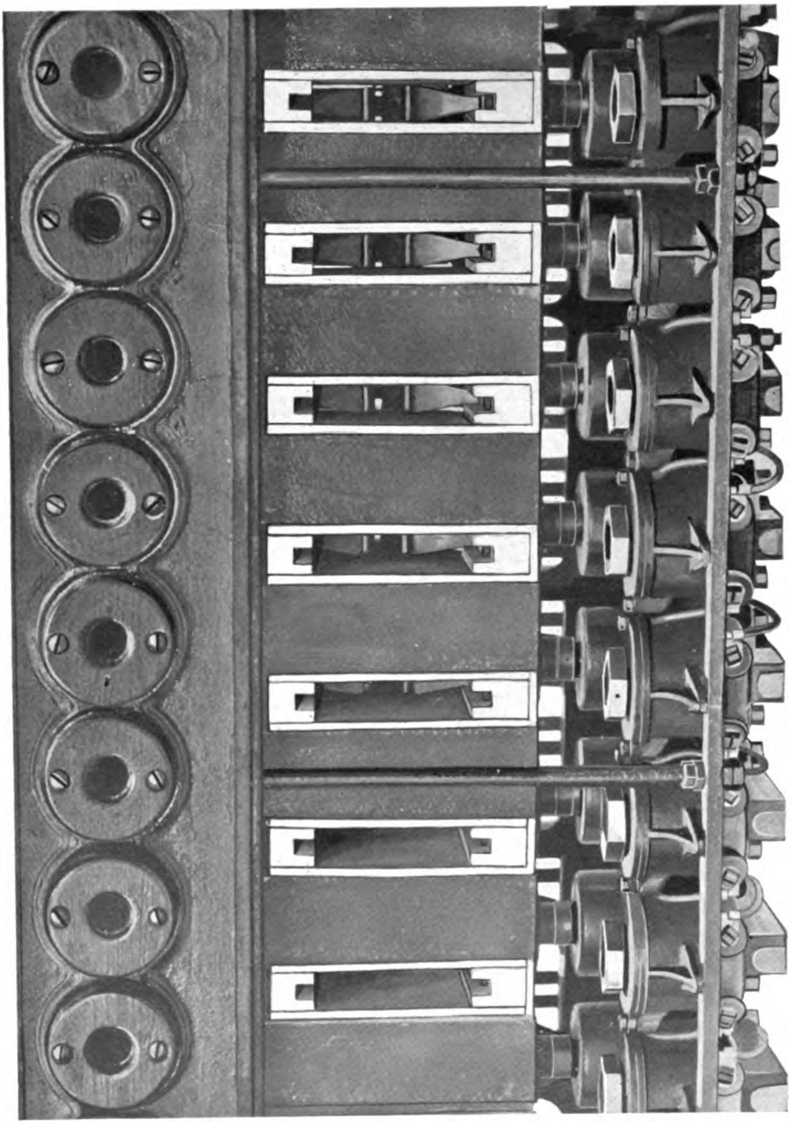


Fig. 15.—View of Switches Used for Regulating Slip

11½ by 95 in., (8.9 by 29.2 by 241 cm.) weighing 1,080 lb. (489 kg.) to a plate $\frac{5}{16}$ in. (7.9 mm.) thick by 12 in. (30.5 cm.) wide, and 1,060 in. (26.9 m.) long. From these curves it will be seen that the maximum current was approximately 4,100 amperes, and the maximum braking current about 2,350 amperes. The maximum speed of the rolls during this test was 86 rev. per min. during the sixth pass, whereas in the first pass the maximum speed was 50 rev. per min. The total time required from beginning to end of the test was 58 seconds, showing a maximum capacity when rolling this size material of

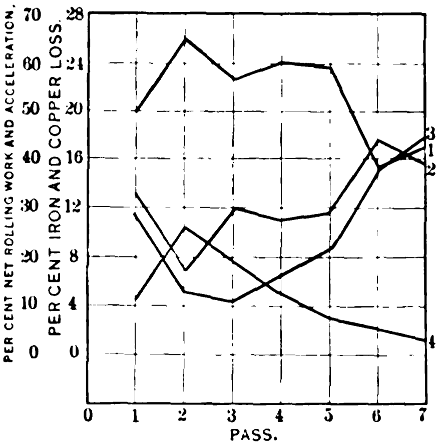


FIG. 17.—ANALYSIS OF POWER INPUT TO ROLL MOTORS WHEN ROLLING PLATE (SEE FIG. 16).

1. Percentage of Net Rolling Work to Total Input.
2. " " Acceleration " " " "
3. " " Friction & Iron Loss " " "
4. " " Copper Losses " " "

Original Slab 3½ by 11½ by 94.9 in. Finished Plate $\frac{5}{16}$ by 12 by 1,016 in.—Temperature of Metal 1,860 to 1,810 deg. fahr.—Composition: Carbon 0.10 %, Phosphor 0.033 %, Manganese 0.51 %, Sulfur 0.044 %.—Ultimate Tensile Strength 53,000 lb. per sq. in.

approximately 30 tons per hour. The temperature of the metal varied during the test from 1,920 deg. fahr. to 1,800 deg. fahr.

In Fig. 17 is shown an analysis of this test, which gives the relation between the total input to the roll motors and the various items. It will be seen that the percentage of net rolling work averages about 55 per cent. The input required for acceleration is about an average of 30 per cent. The loss due to friction of the mill and iron loss in the motors is approximately 10 per cent. The average copper loss is about 5 per cent.

The reason for the very large drop in the percentage of net roll work in the last two passes, is the fact that the draft was comparatively light on these two passes.

The comparatively large proportion of the input required for acceleration shows the importance of keeping the inertia as low as possible, and the great advantage of the voltage control system is that it enables a considerable proportion of this energy to be recovered. In this particular test, the total energy required to accelerate the motors for the seven passes was 11,800 h.p-sec. and there was returned by the motors to the generator 8,317 h.p-sec. or somewhat more than seventy per cent. It should be noted that with this system the energy taken from the generator is only half what it would be if rheostatic control were used and that with the latter system none of the energy would be recovered. In this test, if rheostatic control had been used, the total energy required for acceleration would have been 23,600 h.p-sec. which would have increased the total net input to the motor about 50 per cent.

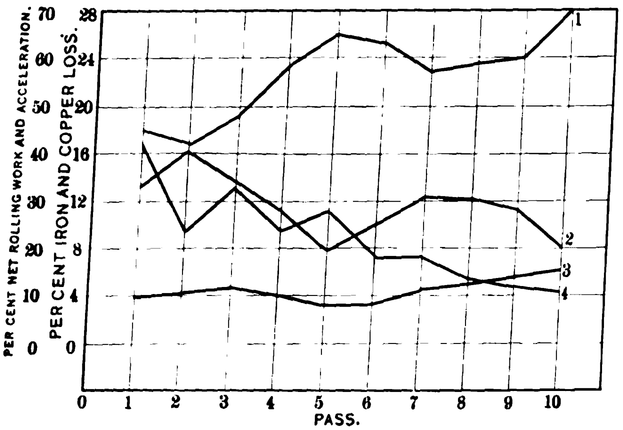
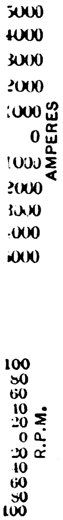


FIG. 19.—ANALYSIS OF POWER INPUT TO ROLL MOTORS WHEN ROLLING PLATE (SEE FIG. 18).

1. Percentage of Net Rolling Work to Total Input.
2. " " Acceleration " " " "
3. " " Friction & Iron Loss " " "
4. " " Copper Losses " " "

Original Slab 3 by 30¼ by 75.9 in. Finished Plate ⅜ by 30 by 612 in. Temperature of Metal 2,030 to 1,200 deg. fahr.—Composition: Carbon 0.18 %, Phosphor 0.025 %, Manganese 0.48 %, Sulfur 0.038 %.—Ultimate Tensile Strength 62,900 lb. per sq. in.

In Fig. 18 are shown the curves when rolling a slab 3 by 30 by 76 in. (7.6 by 76 by 193 cm.) weighing 1,960 lb. (889 kg.) to a plate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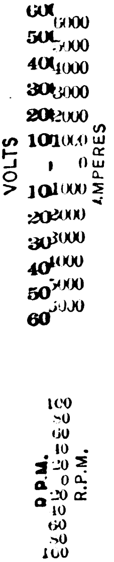
R.P.M.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$\frac{3}{8}$ in. (9.5 mm.) thick by 30 in. (76 cm.) wide. The total time of the test was 100 seconds, indicating a maximum capacity of the mill when rolling these slabs of approximately 36 tons per hour.

It will be seen from these curves that the maximum loads are considerably higher than shown in Fig. 16. In this case, the maximum current input is slightly in excess of 6,000 amperes, and the braking current reaches a maximum of, approximately, 3,150 amperes. The maximum speed of the mill did not exceed 75 rev. per min. during any pass. The temperature of the metal during this test varied from approximately 2,040 deg. fahr. to 1,300 deg. fahr.

In Fig. 19 is shown an analysis of this test, from which it will be seen that the percentage of net rolling work to the total input gradually increased, and the percentage of power required for acceleration, decreased. The copper losses decrease on account of the maximum current being smaller, and naturally the friction loss increases as the mill is running the greater percentage of the time.

The percentage of energy returned by the roll motors was about 62 per cent of the input for acceleration. An examination of a number of other tests taken at random gives the following figures:

	Input for acceleration	Energy returned during braking	Percentage
1.	21,610	14,197	66
2.	21,700	14,215	65.5
3.	18,855	10,657	56.5
4.	18,208	12,512	68.7
5.	17,035	9,105	53.5
6.	20,320	12,449	61.5
7.	23,800	15,546	65.5
8.	18,620	12,111	65
9.	29,195	24,058	82.2
Total	189,343	124,850	66

The power required to displace the metal varies considerably, depending upon the operating conditions. The absolute figures depend upon the temperature of the metal, its composition and the type of mill, etc.

Fig. 20 shows a characteristic curve, when rolling plates on this mill, from which it will be seen that the power required increases very rapidly with the reduction in thickness, this being due to the greater density of the metal, the lower temperature, and the lower rate of displacement.

The total power required for rolling varies considerably, and no definite rule or formula can be produced that will cover all the conditions. The relation of the amount of metal displaced during the earlier passes, to the total, and such items as the temperature, amount of draft, number of passes, etc., make it impossible to give general figures. The net rolling work which is independent of the losses in the equipment also varies widely and a thorough knowledge of the conditions is necessary to predict the power requirement of an installation. In Fig. 21 are shown some curves of the net rolling work per ton plotted against elongation and it will be seen that the variation is considerable. The difference in the total power required may show a much greater variation than given but these curves will indicate in a general way how the net rolling work varies with the displacement of the metal. In a test made when rolling a certain slab, in seven and in fifteen passes, the net rolling work showed a difference of about 10 per cent, but the total input varied about

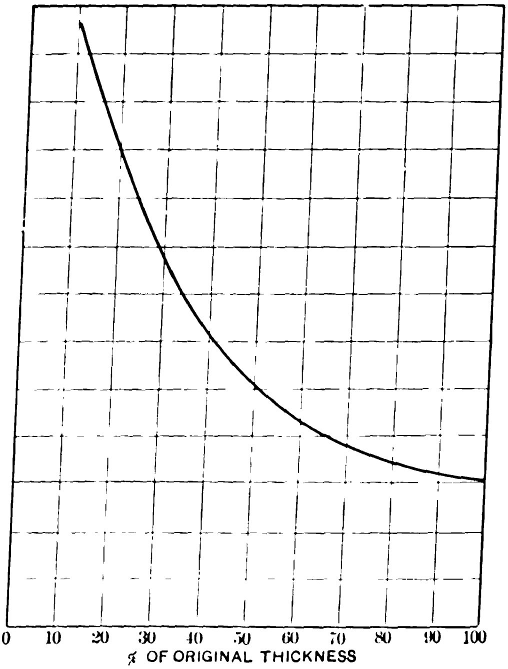

FIG. 20.—CURVE SHOWING INCREASE IN POWER REQUIRED FOR DISPLACING METAL WITH REDUCTION IN AREA.

50 per cent, due to the reduced capacity of the mill when rolling at the lower rate. Such points as these show the importance of a very close examination of operating conditions when designing a mill of this kind, and to insure success an electrically driven reversing rolling mill requires very careful engineering, as the problem is not so much to get a mill that will work, as to get one that will work economically.

At times great stress has been laid upon the advantage and necessity of very rapid acceleration and reversal. The author has pointed out previously that this feature is of little importance, as with a well designed plant the roll motors can be handled more quickly than the material to be rolled. In this mill it is the general practise during the earlier passes, to have the feed rolls running at full speed in the opposite direction to main rolls, so that when the slab leaves the mill, it is returned in the shortest possible time. In spite of this, the main motors are easily capable of reversing in ample time. An examination of a large number of tests on this and other mills, shows that the average rate of acceleration used does not exceed about 20 rev. per min. of the rolls per second, the maximum being about 30 rev. per min. per second. The rate of retardation is, however, very much greater and generally varies between 40 and 50 rev. per min. per second.

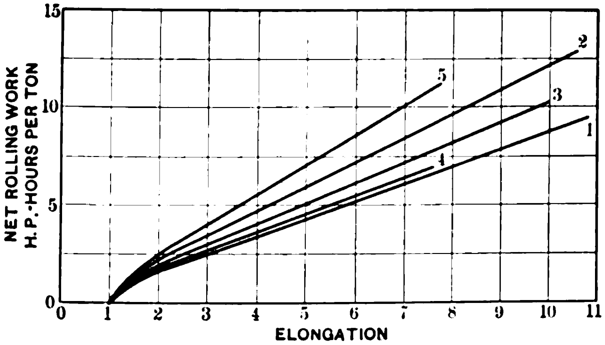

FIG 21.—TYPICAL TESTS SHOWING POWER REQUIRED TO ROLL PLATES FROM SLABS.

	Slab	Plate	Temperature deg. fahr.
1.—4 by 21.5 by	95 in.	to ⅜ by 21¼ in.;	2,160 to 1,536
2.—4 " 21.5 "	60 "	" 5/16 " 21½ "	2,172 " 1,578
3.—4 " 8 "	100 "	" ⅜ " 8¾ "	2,208 " 1,944
4.—6 " 9½ "	90 "	" ¾ " 10 "	2,076 " 1,800
5.—6 " 7¾ "	82 "	" ¾ " 8 "	2,016 " 1,692

The overall efficiency of the plant depends in the first place

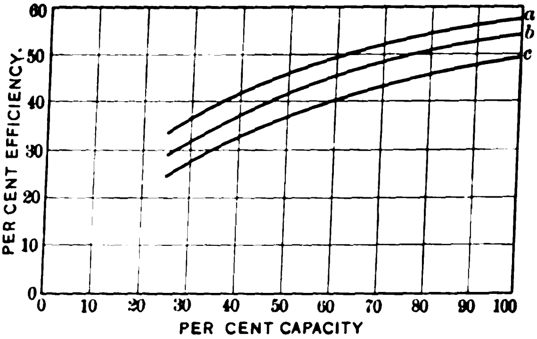

FIG. 22.—OPERATION OF UNIVERSAL REVERSING PLATE MILL UNDER VARIOUS CONDITIONS.

Overall Efficiency, from Input to Power Required to Displace Metal, Including Mill Friction.

a. Rolling Slab 7 by 30¼ by 76 in to ¾ in. Plate.
b. " " 5 " " " " " " " " "
c. " " 3 " " " " " " " " "

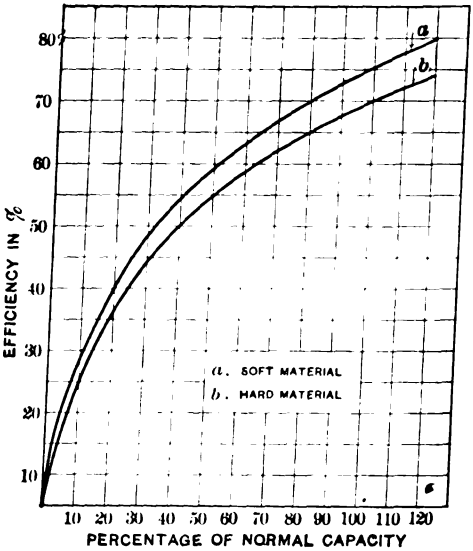

FIG. 23.—CURVES SHOWING THE OVERALL EFFICIENCY OF ELECTRICAL EQUIPMENT AND MILL WHEN ROLLING INGOTS TO BILLETS.

upon the relation of the size of equipment to the material to be rolled. As already pointed out, a mill of this kind cannot be compared to one rolling only a single product, in which case the operating characteristics can be very accurately predicted. As this mill will be often underloaded, the efficiency naturally suffers, which is true, independent of the system of driving. In Fig. 22 are shown some overall efficiencies when rolling slabs of various sizes, and it shows how the results improve with an increasing load. In addition to the losses in the electrical equipment, these curves also allow for the friction of the mill. To show the difference that the underloading, when rolling the smaller slabs, makes upon the efficiency, compared to what can be obtained when the mill is designed for one class of product only, there are presented in Fig. 23 the overall efficiency curves of a blooming mill taken from a previous paper by the author.*

The results obtained from this mill indicate that although the equipment was built six years ago, it compares very favorably with some of the latest designs and is quite capable of meeting the most severe service it may be called upon to perform. In new designs, certain features would be improved upon, with the object of somewhat simplifying the equipment from a manufacturing standpoint, but it is not believed that any great improvement could be made from an operating standpoint, as since it has been in regular service the electrical equipment has given no trouble. The experience gained has shown that the engineers of the Illinois Steel Co. were thoroughly justified in undertaking this pioneer installation without having any precedent whatever to work upon.

* *Electrically Driven Reversing Rolling Mills*, PROCEEDINGS A.I.E.E., June, 1911.

A paper presented at the Pittsburgh Meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 25-27, 1912.

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(Subject to final revision for the Transactions.)

ELECTRIC BRAKING OF INDUCTION MOTORS

BY H. C. SPECHT

For various classes of work—for cranes, hoists, rolling mills, etc.—it is generally required that means be provided for stopping the motor quickly. When the electric power supply to the motor is taken off, the motor speed will gradually slow down, due to the friction load; however, the time required to bring the motor to a standstill by this method is generally too long, and other means have to be applied, stopping by brakes mechanically, electrically, or hand-operated, electric braking by alternating or direct current, etc.

The object of this paper is to discuss electric braking by alternating current and by direct current. If the braking is to be effected by alternating current, it is necessary to reverse the rotating field in the motor. This is ordinarily done on a three-phase motor by reversing two of the primary leads and on a two-phase motor, by reversing the two primary leads of one phase. At the moment of reversal, if the motor is running very near synchronous speed, a frequency is obtained in the secondary approximately twice that of the primary, because the secondary frequency is equal to primary frequency multiplied by the slip, which in this case is approximately two. Further, the secondary voltage changes in the same ratio as the secondary frequency, therefore, if the secondary is running with double frequency, the secondary voltage will be twice the voltage at standstill. This necessitates either that the secondary winding be insulated for the double voltage or that only half voltage be supplied to the primary for braking. On small machines the secondary voltage at standstill is so low that the insulation is strong enough to withstand the double voltage under the required operating conditions.

On large slip ring motors, however, the secondary has to be designed for rather high-voltage, in order to avoid too high currents. A higher voltage requires more insulation, while a greater current requires larger and more expensive switches, heavier leads and larger collector, etc. In order to meet the best conditions, it is necessary to make a fair compromise between the above advantages and disadvantages.

If the rotor is star wound, the voltage to ground can be reduced by grounding the neutral point, thus allowing a decrease of insulation to ground. However, the insulation between phases cannot be reduced, because the voltage between phases does not change by grounding the neutral point.

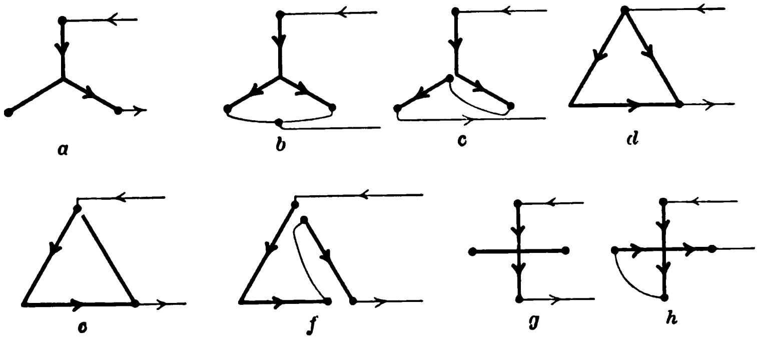

FIG. 1.

On very large motors, of several thousand horse power, it sometimes becomes more desirable to apply half voltage to the primary or to use direct current for braking. In the case of application of half voltage to the primary, auto transformers and extra switches are required, which entails some extra expense and complication. The braking by direct current may be accomplished by connecting the direct-current supply circuit to the primary as shown in Figs. 1a, 1b, 1c, to 1h.

The connections of Fig 1a for three-phase star, 1d for three-phase delta and 1g for two-phase, are generally used on account of their permitting the simplest switching. By using some of the other connections, a little can be gained in regard to the field form and to the least power requirement.

From the preceding, it is to be noted that there are various schemes for electric braking, and that in every case a thorough investigation should be made to see which of the methods will give the best proposition in regard to safety, simplicity, cost and other requirements.

Before the alternating-current braking versus direct-current braking is discussed, a simple method will be given for each of them indicating how to work up the speed-torque and ampere-torque curves. These methods are not claimed to be entirely accurate but are close enough for the practical purpose for which they serve.

METHOD OF BRAKING INDUCTION MOTORS BY ALTERNATING CURRENT

If the secondary ohmic and inductive resistances are reduced to primary terms by multiplying the resistances by the squared ratio of primary to secondary turns, or by squared ratio of the primary to secondary voltage, the induction motor windings may be represented by the diagram of Fig. 2.

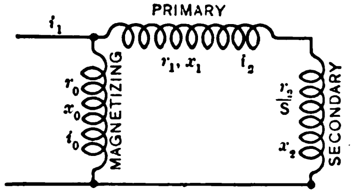

FIG. 2.

The following notation is used:

e_1 = primary voltage between terminals.
e_2 = secondary “ “ “
i_1 = total primary amperes, equivalent to single-phase circuit.
(For three-phase $i_1 = \sqrt{3} \times$ terminal amperes.)
(“ two- “ $i_1 = 2 \times$ “ “
i_0 = total no-load current.
i_2 = “ secondary “
r_1 = primary ohmic resistance between terminals divided by 2.
r_2 = secondary “ “ “ “ “ “ 2.
x_1 = primary inductive “ “ “ “ “ “ 2.
x_2 = secondary “ “ “ “ “ “ 2.
P_L = total watts with motor locked.
T = lb. torque at 1-ft. radius.
S = slip in decimals.
n_0 = revolutions per min. at synchronism.

Assuming that the primary current with motor locked is nearly in phase with the no-load current, then we may write

$$x_1 + x_2 = \frac{\sqrt{[(i_1 - i_0)\, e_2]^2 - P_L^2}}{(i_1 - i_0)^2} \tag{1}$$

$$i_2=\frac{e_1}{\sqrt{\left(r_1+\frac{r_2}{S}\right)^2+(x_1+x_2)^2}} \qquad \textbf{(2)}$$

$$\text{h.p.} = \frac{i_2^2\times(1-S)\times\frac{r_2}{S}}{746}$$

$$T = \frac{\text{h.p.} \times 5250}{n_0\;(1-S)}$$

These two formulas combined give

$$T = \frac{i_2^2\times\frac{r_2}{S}\times 5250}{n_0\times 746}$$

or

$$T=\frac{i_2^2\times\frac{r_2}{S}}{n_0}\times 7.04 \qquad \textbf{(3)}$$

$$S=\frac{i_2^2\times r_2}{n_0\times T}\times 7.04 \qquad \textbf{(4)}$$

By introducing formula (**2**) into formula (**3**) and differentiating the new equation, it will be found that T is maximum when

$$r_1+\frac{r_2}{S}=x_1+x_2$$

Finally, the primary current i_1 is obtained by adding geometrically the magnetizing amperes to the secondary amperes i_2. Those who are familiar with the circle diagram, will obtain the current i_1 very quickly from the diagram (See Fig. 3.) The points C_0 (no load) and C_L (locked) are determined by test or calculation. A vertical line in the center of C_0C_L will pass through the center of the circle. For the above purpose, it is accurate enough to draw another line through C_0 parallel to the base line, then the intersection with the vertical line on C_0C_L will be the center of the circle.

As found analytically, the value for i_1 (see Fig. 4) is as follows

$$i_1=\sqrt{\left[\frac{(x_1+x_2)\times i_2}{\sqrt{\left(r_1+\frac{r_2}{S}\right)^2+x_1+x_2)^2}}\right]^2+\left[\frac{\left(r_1+\frac{r_2}{S}\right)\times i_2}{\sqrt{\left(r_1+\frac{r_2}{S}\right)^2+(x_1+x_2)^2}}\right]^2} \qquad \textbf{(5)}$$

or

$$i_1=\sqrt{(i_2\times\sin\phi_2+i_0)^2+(i_2\times\cos\phi_2)^2}$$

Example

Motor. 2,000-h.p., three-phase, 6,600-volt, 25 cycles, 6-pole, star wound, both primary and secondary.

The tested values for full voltage of 6,600 on primary are:

i_0 = 58 amperes total; no-load watts = 32 kw.
i_L = 1,550 amperes with motor locked.
P_L = 1,950 kw. with motor locked.
r_1 = 0.38 ohms.
e_2 = 1,700 volts.

The resistance of secondary winding per phase at 40 deg. cent. = 0.026 ohms; therefore the secondary resistance reduced to primary terms is

$$r_2 = 0.026 \times \left(\frac{6,600}{1,700}\right)^2 = 0.39 \text{ ohms}$$

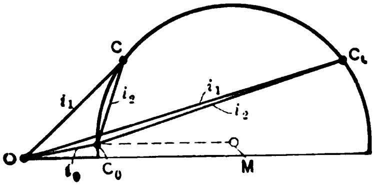

Fig. 3.

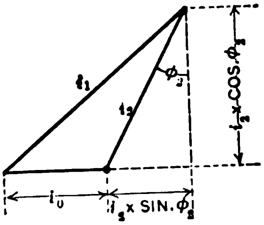

Fig. 4.

In Fig. 5, for the different speed-torque curves 1 to 9, the secondary resistances reduced to primary turns have the following values:

Curve 1.	$r_2 =$ 0.39	ohms without external resistance.				
“ 2.	$r_2 =$ 1.2	“	inclusive of	“		“
“ 3.	$r_2 =$ 2.4	“	“	“	“	“
“ 4.	$r_2 =$ 5.0	“	“	“	“	“
“ 5.	$r_2 =$ 8.0	“	“	“	“	“
“ 6.	$r_2 = 13$	“	“	“	“	“
“ 7.	$r_2 = 20$	“	“	“	“	“
“ 8.	$r_2 = 34$	“	“	“	“	“
“ 9.	$r_2 = 60$	“	“	“	“	“

According to formula (**1**)

$$x_1 + x_2 = \sqrt{\frac{[(1,540 - 58) \times 6,600]^2 - 1,950,000^2}{(1,540 - 58)^2}} = 4.37 \text{ ohms}$$

For $r_2 = 0.39$ and $S = 2$

$$i_2 = \frac{6,600}{\sqrt{\left(0.38+\frac{0.39}{2}\right)^2+4.37^2}} = 1,496 \text{ amperes}$$

$$T = \frac{1,496^2 \times \frac{0.39}{2}}{500} \times 7.04 = 6,100 \text{ lb.}$$

Then for various slips from 2 to 0, the torque curve 1 and the secondary ampere curve are obtained as shown in Fig. 5.

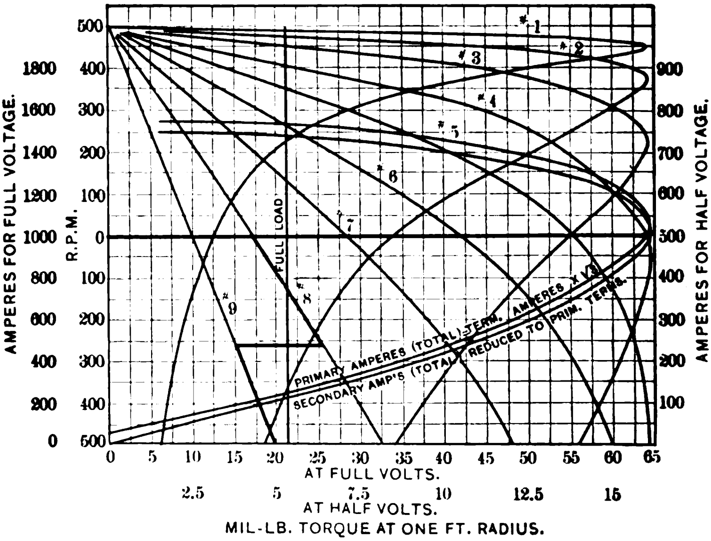

FIG. 5.—AMPERE, SPEED-TORQUE CURVES FOR A-C. EXCITATION.

After the ampere curve for one speed-torque curve is determined, the torque curves for the various values of r_2 with external resistance can be figured quickly according to formula (4). The primary amperes may be obtained either from diagram or may be calculated according to formula (5). It should be noted that the amperes plotted in Fig. 5 are total and not terminal amperes. In order to obtain terminal amperes, the values should be divided by $\sqrt{3}$.

The torque curves above the zero base line (Fig. 5) represent the motive torque curves and those below the zero line, the braking torque curves. All these curves have the ampere curve in common, its lower branch corresponding to the upper branch of the speed-torque curves, and the upper branch of the ampere curve corresponding to the branch of speed-torque curves below the maximum torque, or pull-out point.

Further, it may be noted that for the most effective braking and with the least amount of current, a variation of resistance in the secondary is required. If, for instance, the motor should be stopped with a torque equal to average full load torque, and a current not greatly exceeding the full load current, the resistance should be decreased step by step until the motor stops. This is demonstrated in Fig. 5 by the heavy zigzag line. If a liquid rheostat is used instead of metallic resistance, it would be possible to change the resistance in such a manner that the torque and amperes would remain practically constant during the whole braking period. It is also obvious that unless reversal of the motor is wanted the primary supply circuit has to be disconnected as soon as the motor comes to rest.

In the foregoing example the braking was based on applying full voltage to the primary, and it may be of interest to know how the curves will change if lower voltage is used for the braking. Since the ohmic as well as the inductive resistance remains unchanged, it is clear that the currents vary in the same ratio as the voltage and that the torque changes with the square of the voltage or amperes. Therefore, the same curves which have been worked up for full voltage can also be used for lower voltages simply by changing the ampere scale in the ratio of the voltage change and the torque scale by the squared ratio of the voltage change. This is done in Fig. 5 for half voltage.

Finally it can be seen from Fig. 5 and formula (**3**) that for half the secondary resistance and the same current as for full voltage, the torque is reduced only to half the full voltage torque value. Therefore, in order to brake the motor at half voltage with full load current and half the full load torque, the secondary resistance must be half that at full voltage. This torque, however, can be obtained only when the motor has at full voltage a maximum torque, or pull-out torque, of at least twice the full load torque, because the maximum torque at half voltage will be only one-quarter of that at full voltage.

If the motor has a squirrel cage rotor, it is obvious that only one speed-torque curve can be obtained, due to the fixed resistance in the secondary, and in order to obtain a good torque for braking, starting, or reversing, without an excessive current, the secondary winding must have a high resistance. Consequently this kind of motor is very inefficient under running conditions, due to the high secondary ohmic drop and should, therefore, be applied only for very intermittent service, for elevators, cranes, hoist or similar work.

METHOD OF BRAKING INDUCTION MOTORS BY DIRECT CURRENT

The following notation is used:

r_2 = secondary ohmic resistance measured between terminals and divided by 2.

x = inductive resistance at synchronism.

S = slip in decimals ($S = 0$ at synchronous speed of motor).
($S = 1$ " standstill).

n_0 = revolutions per min. at synchronism.

n = " " " " which motor runs.

e_2 = secondary voltage between terminals at no-load speed.

i_2 = total secondary current equivalent to single-phase.
(For three-phase i_2 = terminal amperes $\times \sqrt{3}$)
" two- " i_2 = " " $\times$ 2)

i_s = total secondary short-circuit current for inductive resistance only.

i_1 = total primary amperes.

T = torque in lb. at 1-ft. radius.

i_0 = direct current for exciting.

t_1 = number of turns per phase in primary.

t_2 = " " " " " " secondary.

For the direct current for exciting, an alternating current can be substituted, having a value of $\frac{1}{\sqrt{2}}$ times the direct current, and then, for synchronous speed, the voltage and short-circuit current in the secondary can be determined by transformation. The short-circuit current is equal to the equivalent alternating magnetizing current, reduced to the secondary turns. The secondary open-circuit voltage obtained by alternating current excitation at standstill is the same as that obtained by the equivalent direct-current excitation when running at synchronism. However, in determining the corresponding alternating short-circuit current, the distribution and the amount of winding which is excited by direct current has to be taken into consideration, *i.e.*, the current must be multiplied by another factor (C) besides $\frac{1}{\sqrt{2}}$. For example, the factor C for a three-phase winding of which two of the phases are excited by direct current (see Figs. 1a and 1c) is equal to 1.15.

According to the foregoing, the total short-circuit current in a three-phase secondary at synchronism which would be obtained if the rotor had inductive resistance only and no ohmic resistance, is

$$i_s = \frac{i_0 \sqrt{3}}{\sqrt{2}} \times \frac{t_1}{t_2} \times C \qquad (6)$$

and the equivalent primary alternating current is

$$\left.\begin{array}{ll} i_1 = \frac{i_0 \sqrt{3}}{\sqrt{2}} \times C & \text{for three-phase primary} \\ i_1 = \frac{i_0\, 2}{\sqrt{2}} \times C & \text{" two- " "} \end{array}\right\} \qquad (7)$$

After having determined the primary current, the corresponding secondary voltage e_2 can be read off on the open alternating-current saturation curve, or in case neither the alternating-current nor the direct-current saturation curve is available, the secondary voltage can easily be calculated.

After having determined the secondary short-circuit current and the open-circuit secondary voltage e_2, the inductive resistance x is found by

$$x = \frac{e_2}{i_s} \qquad (8)$$

Finally the secondary current and torque for various secondary resistances and slips are given approximately by

$$i_2 = \frac{e_2}{\sqrt{\left(\frac{r_2}{S}\right)^2 + x^2}} \qquad (9)$$

$$T = \frac{i_2^2\, r_2}{n} \times 7.04 \qquad (10)$$

or

$$S = \frac{n_0\, T}{i_2^2\, r_2} \times 7.04 \qquad (11)$$

By substituting the value of i_2 of formula (**9**) in formula (**10**) and differentiating this new equation, it will be found that the maximum torque is always attained when $\frac{r_2}{S} = x$

EXAMPLE

In order to obtain a comparison between alternating-current and direct-current braking the same 2,000-h.p. motor is selected for example.

Assuming that the primary is excited by direct current across two terminals of the star winding and that this current is 100 amperes, then, according to formulas (6) and (7)

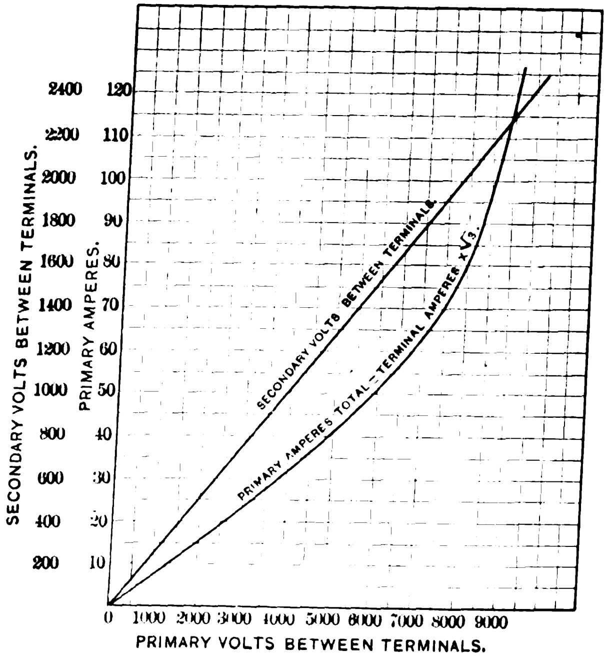

FIG. 6.—SATURATION CURVES FOR A-C. EXCITATION.
Motor Standing Still. Secondary Open Circuited.

$$i_s = \frac{100\sqrt{3}}{\sqrt{2}} \times \frac{6,600}{1,700} \times 1.15 = 550 \text{ amperes total}$$

$$i_1 = \frac{100\sqrt{3}}{\sqrt{2}} \times 1.15 = 141.7 \text{ amperes total}$$

The corresponding secondary voltage e_2 for this current $i_1 = 141.7$ is found from the saturation curve of Fig. 6.

$$e_2 = 2,420 \text{ volts}$$

Then the inductive resistance x is equal to

$$x=\frac{2,420}{550}=4.4 \text{ ohms}$$

For the various secondary resistances r_2, the following values are selected: (see Fig. 7)

Curve 1. $r_2=0.026$ ohms without external resistance.
" 2. $r_2=0.5$ " including " "
" 3. $r_2=1.0$ " " "
" 4. $r_2=2.0$ " " " "
" 5. $r_2=3.0$ " " " "

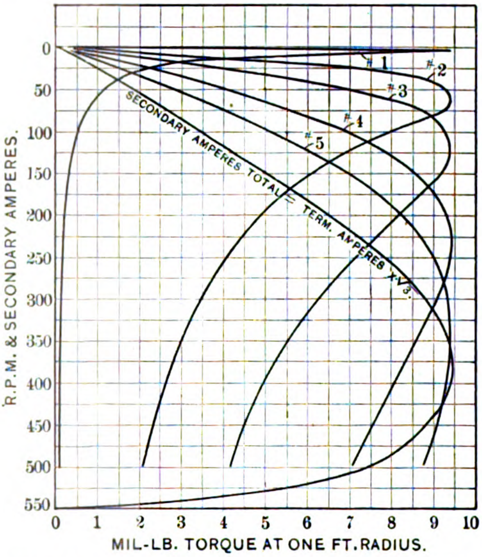

FIG. 7.—AMPERE, SPEED-TORQUE CURVES.
For Direct-Current Excitation of 100 Amperes.

For $S=1$ and $r_2=0.5$ ohms the secondary current i_2 and torque T are

$$i_2=\frac{2,420}{\sqrt{\left(\frac{0.5}{1}\right)^2+4.4^2}}=548 \text{ amperes}$$

$$T=\frac{548^2\times 0.5}{500}\times 7.04=2,120 \text{ lb.}$$

Then in the same manner the currents and torques for other slips and resistances may be figured, and in Fig. 7 the results are shown. It will be noted that the different speed-torque curves have the ampere curve in common, as in the case of braking with alternating current.

Curve 1 (without external resistances) shows that the torque at 500 revolutions per minute is nearly zero and increases very slowly as the speed decreases, except that below 50 revolutions per minute the torque increases much faster. At about three revolutions per minute the torque reaches almost instantly the maximum value of 9,400 lb. (4,260 kg.) and from then on until standstill the torque drops very rapidly to zero value. Therefore, this speed-torque curve is of no practical value, and in order to obtain good braking torque over a wider range of speed it is necessary to insert a fairly large resistance.

Further, the curves in Fig. 7 show that the maximum torque obtainable with an exciting current of 100 amperes is not even quite half the full load torque and that the open-circuit secondary voltage at synchronism is 42 per cent greater than the voltage at standstill with 6,600 volts (alternating current) on the primary.

A greater torque could be obtained by increasing the exciting current, which, however, would give a still higher secondary voltage and a stronger field, thus increasing the inevitable unbalanced pull and the danger of greater potential rise in case any of the circuits should break. The conditions for direct-current braking of this particular motor are very poor, because the magnetizing or no-load alternating current is so very small compared to the full load current. However, most of the induction motors have a comparatively greater no-load current and consequently give more favorable results than in the case of this 2,000-h.p. motor. Nevertheless, without running too great a risk in regard to high secondary voltage and great unbalanced pull, the very best torque which can ordinarily be obtained by braking with direct-current is not greater than full load torque.

As a check on the foregoing results for the secondary voltage e_2 and short-circuit current i_s, the same motor was driven by another motor at synchronous speed, the primary was excited by direct current and the open-circuit secondary voltage measured. Then the secondary circuit was closed and short-circuit amperes measured. The results are shown in Fig. 8. Curves 1 and 3 in this figure correspond to an excitation of two-phases, according to connection of Fig. 1a, and curves 2, 4 and 5 correspond to excitation of all three phases according to connection of Fig. 1c.

Curve 5 represents the saturation which is obtained by having two of the secondary terminals short-circuited and the voltage measured across the terminal of the open phase and one of the short-circuited phase terminals. It is to be noted that this gives an increase in voltage of approximately 25 per cent over the saturation curve (4) with all three phases in the secondary open-circuited.

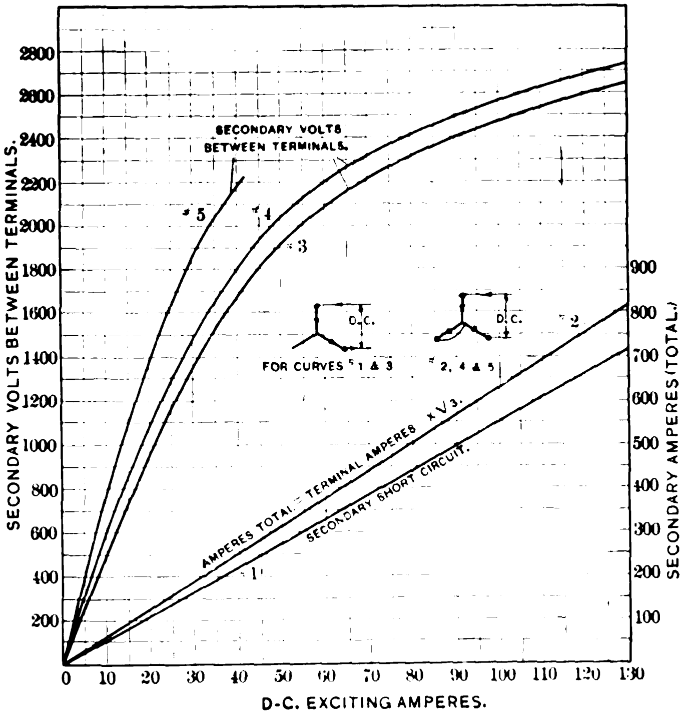

FIG. 8.—SATURATION CURVES, WITH DIRECT-CURRENT EXCITATION.

Comparing now the results of the direct-current braking with those of the alternating-current braking, the following may be said:

1. The braking torque obtainable by alternating current, even with only half the primary voltage, is, as a rule, considerably greater than with direct current.

2. In braking with alternating current, the line circuit has to be taken off from the motor as soon as the motor comes to a

stop, otherwise the motor will reverse, whereas in braking with direct current the motor comes to rest only and will not reverse whether the excitation is taken off the motor or not.

3. With alternating current, it is an easy matter to brake the motor with a strong and practically constant torque during the whole period of stopping, whereas with direct-current excitation it is somewhat difficult to obtain good braking torque near standstill due to the rapid decrease in torque from maximum to zero, because, no matter how great the direct exciting current is at standstill, no torque can be developed.

4. If it is desired to brake the motor with full load torque by means of direct current, the secondary voltage at synchronism will not be far from double voltage, which is the same value that would be obtained by braking the motor with alternating current at full primary voltage.

5. Since the magnetic field for direct-current braking has to be much stronger than for alternating-current braking, the danger of serious potential rise, due to breaking of any of the circuits, is greater with direct-current excitation than with alternating current.

6. For the same reason given in the foregoing paragraph, the danger of heavy unbalanced pull is greater with direct current than with alternating current.

7. The only great advantage of braking with direct current is the small electric energy which is needed. Only the C^2R losses of the primary are to be supplied when direct current is used, while with alternating current the full power has to be supplied that the motor would require for developing an equal torque at normal operating condition.

From the foregoing, it is obvious that in cases where infrequent braking is called for, braking by alternating current has, as a rule, preference over the direct-current braking method. However, in cases, as on hoists, cranes, etc., where very frequent braking takes place, the direct current may be preferable on account of saving in power.

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OZONE: ITS PROPERTIES AND COMMERCIAL PRODUCTION

BY MILTON W. FRANKLIN

The importance of ozone as an industrial factor in certain lines of engineering is becoming appreciated quite rapidly. The relatively large number of patents which are being applied for, the increasing number of advertisements which are appearing and the character and standing of the electrical manufacturers who have entered the field, all point to a realization of Berthelot's prediction that ozone was destined to enjoy a great vogue in its application in the arts and sciences. The commercial future of ozone may be regarded as assured. The many actual applications which have already been made and the numberless fields for its logical invasion, together with recent developments of perfected ozone generators all indicate the growing consideration which this reagent is gaining for itself.

Ozone has been known since 1785 when Van Marum noted the peculiar smell which resulted whenever a static electrical machine was operated, and while its identity was fully established by Schoenbein in 1845 and a method for its analytical determination was developed by the same investigator, it has not enjoyed any extensive application, excepting on an experimental scale, until approximately within the last ten years. This delayed recognition may be attributed to the lack, at the time, of perfected ozone generating apparatus and to the absence of commercial electricity.

The primitive ozone apparatus was designed to produce a phenomenon, the discharge of electricity through air, which, it had been noticed, was ordinarily accompanied by the production of ozone.

It was seen early that the amount of ozone produced in the naked arc, either high or low tension, was relatively small as compared with that due to the brush or "silent" discharge, and the constructional and manipulative difficulties accompanying the production of and operation of static condensers are probably responsible for the introduction of a solid dielectric interpolated between the statically charged plates of the modern ozone generator.

There does not appear to have been any very erudite opinion on the ***modus operandi*** of ozone generation among the early designers and the prevalence of the type in question, viz., that with smooth electrodes and solid dielectrics, seems to be due to a desire to produce an electric field of considerable extent, in which the discharge should be uniformly distributed.

It has also been apparent for some time that, at certain elevated intensities, the appearance of noxious nitrogen oxides became manifest, and the objectionable circumstances was ameliorated by lessening the potential difference and increasing the interpolar spacing of the electrodes.

The scientific design of ozone generators as distinguished from the purely empirical method is of very recent inception and its beginning, naturally, is somewhat obscure. There have appeared creditable machines for the purpose, in advance of any theoretical information as to the principal involved.

PRODUCTION OF OZONE: OZONE GENERATORS

Ozone may be produced by chemical means, by the electrolysis of water and by the action of the electrostatic field on air or on oxygen.

Slow oxydations, as of phosphorous, produce ozone. The process is a curious one and has been studied by Schoenbein who noticed that when certain substances are oxidized by air a portion of the oxygen combines directly with the substance undergoing oxydation, while another portion of the oxygen forms ozone. Thus ozone is formed during the oxidation of numerous substances. Schoenbein also enunciated the law that precisely the same amount of oxygen is converted into ozone as combines with the substance oxidized. This law has been verified by several other observers for phosphorous, aldehyde, triethylphosphine, turpentine, amylene and numerous other organic substances, and for sodium sulphite, ammoniacal cuprous oxide, etc., in the process of auto-oxidation.

About the only practical application, however, of the chemical production of ozone, has been by means of fluorine. Moisson has obtained fluorine by the electrolysis of anhydrous hydrofluoric acid. Fluorine attacks powerfully all organic materials and decomposes water, combining with its hydrogen to form hydrofluoric acid and at low temperatures, the oxygen forms ozone. The reaction is as follows:

$$3\ H_2O + 6\ Fl = 6HFl + O_3$$

In the preparation of ozone by the decomposition of water by fluorine, the fluorine is introduced in a thin stream into the water which is maintained at a temperature of 0°C.

Recent improvements in fluorine generators have made the method practicable but it does not compare in economy with the electrical methods of ozone production.

The Electrolytic Production of Ozone. Ozone is formed along with the oxygen in water electrolysis. The presence of ozone accounts for the low reading for oxygen obtained when the electrolyte is too strong in sulphuric acid and the current density too high.

The first recorded observation of ozone in water electrolysis was by Schoenbein in 1840. More recently ozone has been obtained by alternating current electrolysis of acidulated water.

In some of the electrolytic processes at Niagara Falls the presence of ozone has been strongly manifest, though there is no recorded mention of its having been used for any industrial purpose.

In the production of ozone by electrolysis, the anode must be of some substance not oxidizable, such as platinum, gold, etc., and the electrolyte must contain no matter which is capable of combining with the ozone.

In certain special applications, ozone prepared by electrolysis seems to be more active and suitable than that prepared by the commoner electrical methods, but the reasons are obscure and the cases uncertain. The method is not economical and has found no general application though higher concentrations are obtainable than by other ordinary procedures.

Electrostatic Production of Ozone. The common method of ozone production for industrial purposes is by the action of the electrostatic field on air or oxygen.

The types of machines that have been devised are almost without number, ranging from those utilizing the high frequency discharges of the Oudin and Tesla resonators to those making use of the "effluve" or the silent discharge of a leaky condenser with or without solid dielectrics. The variations and the combinations of the fundamental types are too numerous to mention, even, and only a few or the more useful and striking examples will be described.

The ultimate theory of the electrical formation of ozone is still somewhat obscure and it may be said that whatever definite information there is on the subject is rather of a negative than of a positive character: *e.g.*, Warburg and Leithauser have shown that the process is not an electrolytic one. The equivalent weight of ozone is 24, and, therefore, if the process were an electrolytic one it would require the electrochemical equivalent, 96,540 coulombs, for the production of one mole, 24 gm., of ozone. In actual practise, however, as much as 130 gm. per kw-hr. has been obtained, which under the conditions of the operation corresponds with 240 coulombs only, or the equivalent of ozone has been obtained with about 44 coulombs. This number is far too different from the electrochemical equivalent to be a matter of experimental variation.

The view is generally held that the process is one of ionization and recombination. There appears a disassociation of the oxygen as soon as the action of the electrostatic field becomes sufficiently intense to cause ionization by collision, and there result numbers of ions from the disassociated molecules. These ions attach themselves to the molecules with which they must inevitably collide and thus form ozone which, on this view, may be composed of aggregates of odd numbers of atoms of the general formula, $O_{(2n+1)}$.

The relation between the quantity of ozone produced and the quantity of current has been the subject of considerable speculation, but no perfectly satisfactory hypothesis has been advanced. Warburg has advanced the theory that the ozone is formed by those electrons which have attained a certain critical velocity., *viz.*, that at which luminosity appears.

Ozone is an endothermic compound and, therefore, the equilibrium concentration is greatly increased under certain circumstances, as for example, the influence of the electrostatic field especially if the temperature is kept low so as to lessen the destructive forces as compared with the constructive forces.

The silent discharge or "effluve" of the French writers, is the conduction of electricity through gases at low and moderate pressure. The phenomena vary with the electrical and physical dimensions, and with the conditions generally, of the electrical and gas pressure. The discharge is quiet and the gas attains a dark violet luminosity. If the pressure is comparatively low the discharge between a point and a plate will be of this nature but the electrical polarity of the point exerts an influence. The discharge between plane parallel or curved concentric surfaces is generally of this character, and when a dielectric is interposed between the plates, the formation of sparks is effectually prevented.

The question as to whether or not a dielectric should be used has been the cause of considerable experimentation and discussion but the general consensus of opinion at present is that the use of the dielectric increases the efficiency of the ozonator.

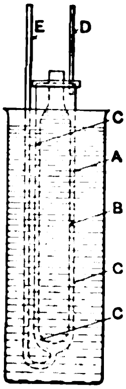

Fig. 1

Forms of Ozonators

One of the first ozonators with which experiments on anything like a large scale were carried out was introduced by Berthelot in 1876. This ozonator, Fig. 1, consists essentially of two concentric glass tubes *a b* closed at one end and forming between them the free annular space *c*, which is closed at the top by welding the two tubes together. Air or oxygen is admitted to the annular space by the inlet tube, *d*, and withdrawn at the outlet tube *e*. The inner tube *b* is filled with dilute sulphuric acid, and the outer tube, *a*, is plunged into a vessel containing the same, thus enabling the temperature of the system to be controlled.

The poles are formed by the fluid in the inner tube and that surrounding the outer tube. The electrical connections are made by means of two platinum wires dipping into the two acids respectively and connected to the terminals of the sources of current. When the potential difference is sufficiently high there is a luminous silent discharge in the gas in the annular space between the tubes and there is the formation of ozone.

The general principles of this ozonator have been retained in some of the later commercial types, *e.g.*, the Gerard ozonators.

The Siemens and Halske ozonators, Fig. 2, consist of a central metallic cylinder surrounded by an annular air space in which the electrical discharge takes place and through which the gas to be ozonized is passed. The outer boundary of the air space is a cylinder, concentric with the central core and in turn surrounded by a water jacket which serves to keep the temperature within proper limits. The potential is applied between the central core and the water surrounding the outer wall of the air space, and the latter may be of glass or of metal. In the latter case there is supplied a lining of glass which forms the dielectric. This type of ozonator has had considerable commercial application and is used in the installations at Wiesbaden-Padderborn, Saint Petersburg, etc. The whole ozonator is enclosed in a metallic case which is furnished with inlet and outlet tubes for the air and the ozone. The Gerard ozonator has appeared in several commercial forms which differ from each other in minor constructional details. It consists essentially, of two concentric glass tubes about one meter in length, and the outer tube has a diameter of approximately 8 cm. The annular space between the tubes in which electrical phenomena take place varies from three to five mm. in the various modifications. The electrodes are metallic coatings affixed to the outer surface of the outer tube and to the inner surface of the inner tube respectively.

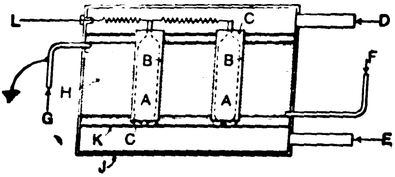

FIG. 2.

A—inner electrode, *B*—outer tube, *C*—ozone space, *D*—air inlet, *E*—air outlet, *F*—water inlet, *G*—water outlet, *H*—water, *J*—outer casing, *K*—partition, *L*—high-tension lead.

An example of an ozonator without dielectrics is that of De Frise, Fig. 3. This consists of a trough, semicylindrical in cross section and furnished with a water jacket for cooling. A glass cover closes the trough and from this are suspended a number of semicircular metallic disks which may have smooth or serrated edges. These disks are arranged in parallel planes and are spaced at about one cm. The flat edges are fastened to the glass cover and the curved edges together form a ribbed semicylindrical surface, which, when in position, comes to within about five mm. of the bottom of the trough, with which it is concentric. The

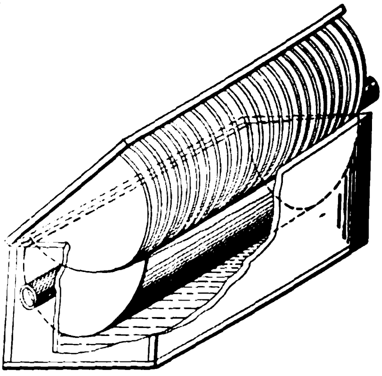

FIG. 3.

electrical discharge takes place between the edges of these disks and the bottom of the trough, and the air to be ozonized is drawn through the space which intervenes.

There have appeared from time to time, ozonators with devices for obviating the necessity for the solid dielectric. Otto has designed several in which the electrodes move with respect to each other, or in which one moves and the other remains stationary. Fig. 4 is a diagram of one of these. It consists of a metallic casing which forms one of the electrodes, and a series of metallic disks mounted parallel on a shaft by which they are rotated. The disks each have two sectoral windows, diametrically opposite each other, cut from them, and when assembled, form the other electrode. The disks are beveled at the edges, and the windows are staggered with respect to the disks which are adjacent. This arrangement assures that if a spark forms at any point, it will be drawn out and ruptured by the rotation of the disks.

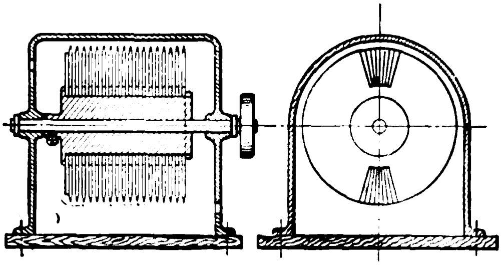

FIG. 4.

Ozonators without solid dielectrics and with rotating electrodes have as yet enjoyed no very extensive application. The absence of the dielectric seems to favor the production of nitrous oxides notwithstanding the precautions to the contrary, and the extra power required to rotate the electrodes does not seem to be compensated for by any corresponding gain in another direction.

Besides the ozonators which have been mentioned there have appeared numerous others, as those of Andreoli, Tisley, D'Arsonval, Tindal, Otto, Vosmaer, etc., but all of the successful commercial types have tended to the same general design, namely, metallic electrodes with smooth surfaces and interpolated solid dielectrics.

All the ozonators which have been mentioned above are for the production of ozone on a large scale and at relatively high concentrations, and are in general intended for the purification of drinking water and for analagous industrial applications. Latterly, however, the subject of purifying and refreshing the air of localities which suffer from overcrowding, inadequate ventilation, and the introduction into the air of the noxious products of industrial activity, has engaged the attention of sanitarians to a considerable extent. From a consideration of the theoretical causes of the objectionable character of such air and the essential properties of ozone it has become evident to many experts that ozone offers a remedy for the conditions, and one which possesses many advantages of simplicity, efficiency and economy. There has resulted, in consequence, the development of numerous ozonators for the specific purpose of treating the air of populated spaces.

The requirements in these small ozonators differ in several important particulars from those demanded in the larger machines. The instruments are, in general, put into the hands of unskilled persons and they must, therefore, be simple, durable, self-contained and automatic to the greatest obtainable degree. They must be small, fireproof, free from danger and reliable in operation, and all of these properties must be possessed in a measure far surpassing that required in the larger machines intended for operation by skilled electricians. Under no circumstances must they produce nitrogen oxides and this prohibition also precludes the employment of means for removing the objectionable by-products after they may have been formed in the machine.

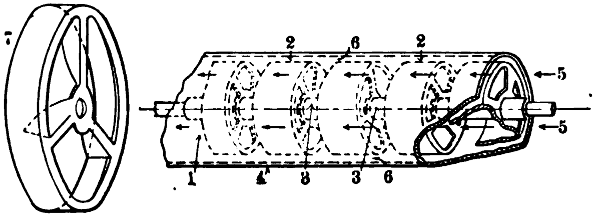

FIG. 5.

1—glass tube; 2—aluminum cylinders, inner electrode; 3—spacing collars; 4—metal coating, outer electrode; 5—direction of air flow; 6—air-gap; 7—enlarged view of 2.

Most of these desiderata such as safety, durability, simplicity, space economy, etc., etc., may be obtained by operating at low voltages. To employ low voltages at the frequencies commonly met with in commercial installations, and at the same time to obtain the electrostatic field intensities requisite for the production of ozone, the length of the field in a direction normal to the electrode surfaces must be shortened. This shortening ordinarily has the disadvantage that it lessens the volume of air that may be treated with respect to a given area of electrostatic field, and consequently affects adversely the consideration of space economy. Fig. 5 shows a method by which the field has been shortened to a value limited only by the inability of the glass-blower to produce more accurate tubes, without at the same time curtailing the ozone production capacity of the ozonator. The cut represents one form of unit used in the General Electric air ozonators, an assembled machine being shown in Fig. 6.

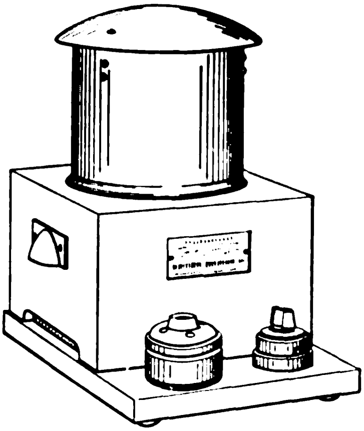

FIG. 6.—ALTERNATING-CURRENT HOUSEHOLD OZONATOR.

Referring to Fig. 5, the potential is applied between the metallic coating of the glass tube, 1, and the metallic inner electrode, 2, which is formed of a series of cups of a special design. The electrostatic field is formed in the space, 7, which has a clearance of the order of 0.4 mm. so that with comparatively low voltages the potential gradient may be extremely high. The air to be ozonized is blown along the axis as shown by the arrows, 5, and the peculiar vane shape of the spokes of the cupped electrodes causes a constant intercommunication between the new air and that which has been ozonized in the ozone spaces.

Ozone is an allotropic form of oxygen with the formula O_3, as was established by Schoenbein. The nature of ozone was for a long time debated but the researches of Andrews and Tait, Marignac and De la Rive, Brodie, Fremy and Becquerel and particularly those of Schoenbein showed conclusively that when oxygen was converted into ozone, the volume was reduced one-third, and analysis failed to show the appearance of combinations with other elements. Ozone is a faintly bluish gas with a characteristic smell and it was this circumstance that led to its discovery. It has never been obtained in the pure state but is always mixed with oxygen from which it is derived.

Hautefeuille and Chappuis, on compressing ozone to 125 atmospheres at the temperature of boiling ethylene (−103 deg.) have obtained a dark blue liquid with highly magnetic properties. The compressed gas above the liquid was also of the same intense blue color, and both the compressed gas and the liquid were highly explosive. When the pressure is removed and the temperature allowed to rise, the liquid soon evaporates.

Ozone is relatively stable at ordinary temperatures when remote from organic or other oxidizable substances, but becomes unstable at elevated temperatures and decomposes into ordinary oxygen. The decomposition is instantaneous at 260 deg.

Ozone possesses enormous chemical activity as compared with ordinary oxygen, for the reason that it parts with the extra atom of oxygen very readily. It is an endothermic compound and the endothermic heat has been investigated by numerous chemists including Berthelot, van der Meulen, Jahn and others. The mean value of the endothermic heat as obtained by numerous methods is 33.380 calories per grammolecule.

Ozone is only slightly soluble in water. Recently, E. Maufang has investigated the subject and found that the solubility of ozone in water is proportional to the temperature and pressure, and conditioned by the chemical composition of the water; a concentration of 1.5 to 10 mg. per liter of water may be regarded as the solubility coefficient at ordinary temperatures (2 deg.−28 deg.)

The chemical analysis and the volumetric determination of ozone as worked out by Schoenbein in 1845 was the subject of some difference of opinion and discussion, but in 1872, Brodie verified the results and established the theory. Later, 1901, the discussion having again arisen, Ladenburg and Quasig covered the same ground with the same result, though they appear to have been unacquainted with the work of Brodie. Treadwell and Anneler, in 1905, checked all previous results and finally established the correctness of the method of analysis which is now in general use.

The analysis depends on the following reactions:

$$2\,KI + O_3 + H_2O = 2\,KOH + I_2 + O_2 \qquad (1)$$

and

$$2\,Na_2S_2O_3 + I_2 + 2\,KOH + H_2SO_4 = Na_2S_4O_6 + 2\,NaI + K_2SO_4 + 2\,H_2O \qquad (2)$$

which in actual practice reduce to the following volumetric equation:

$$1000 \text{ cc. } \frac{N}{10} Na_2S_2O_3 = \frac{O_3}{20} = \frac{48}{20} = 2.4 \text{ gm. } O_3. \qquad (3)$$

The commercial value of ozone consists in the fact that it is so powerful an oxidizing agent that many of the reactions of oxidation which take place with ordinary oxygen only on the addition of heat, may be effected with ozone without previous heating, and in a much shorter time.

The many applications of ozone have been adequately treated in previous publications* and aside from the purification of air and water they are of general interest to the chemist rather than to the engineer, and will not be dilated on here.

The fact that there was transacted about seven million dollars' worth of business in ozone apparatus in Europe last year indicates the trend of modern thought with respect to ozone.

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*M. W. Franklin in *N. Y. Medical Journal*, April 8, 1911, "Ozone." M. O. Troy in *General Electric Review*, August 1911, "The Action of Ozone on Air."

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COMPRESSION CHAMBER LIGHTNING ARRESTER AND THE PROTECTION OF DISTRIBUTION CIRCUITS

BY E. E. F. CREIGHTON AND F. R. SHAVOR

The object of this paper is to describe a new form of lightning arrester in which the attainment of low cost was the principal motive of the design, and to note the improvement the application of this arrester will have on the methods and efficiencies of protection of distribution circuits. This is the first step toward the complete solution of the problem of discontinuity of service and injury of transformers due to lightning. This is to be the subject of continuous study until the desirable condition is reached. The end seems already in view although not all of the material is sufficiently completed to be made a part of this paper.

During the past few years relatively little experimental work has been devoted to the multigap lightning arrester. Even now after much further experimentation no principle stated then is rendered questionable. One new feature in the operation of the arrester has been added. If there is apparently a partial or temporary recession of practice previously laid down it comes entirely from the desire to lower costs, and other changes are made to minimize the effect of the recession.

There has been a demand for years for an inexpensive arrester for the protection of small installations where the revenue from, and cost of the installation would not justify the expenditure for the best arrester.

Furthermore, the best practise in protecting 2300-volt pole transformers *absolutely demands* that the arrester be placed on the same pole with the transformer. To fulfill this condition an inexpensive arrester is necessary. The practice of placing three or four arresters per mile regardless of the location of the transformers is ineffective. Experience shows that lightning potentials are very much concentrated, and an arrester placed even at the distance of an adjacent pole from a transformer may be rendered unprotective. This is a condition which can be produced in the laboratory experiments.

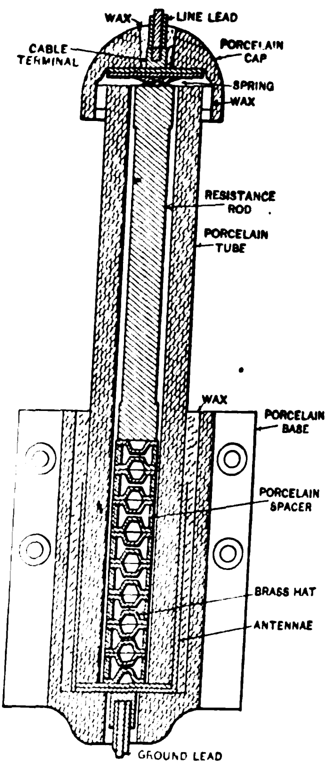

Fig. 1.—Detailed Cross Section of Arrester.

Construction of the Compression Chamber Arrester

The compression chamber arrester is a particular design of the well-known multigap arrester. The cost of this arrester has been reduced principally by making it self-housed. The other standard design of multigap arrester was made for indoor work, and when used outdoors requires a wooden box for housing it. This wooden box is comparable in expense to the arrester itself.

Fig. 1 shows the arrangement of the parts of the compression chamber arrester. Fig. 2 shows the assembled arrester and Fig. 3 the disassembled parts. On the outside, Fig. 1, there is a porcelain base with four screw holes to connect it to a cross-arm. Immediately inside of this base are the *antennae*. The antennae vary in form in different arresters, but in this case they consist of two metal strips in the form of a U that fit inside of the holder or base. Inside of these antennæ is placed a straight porcelain tube. The porcelain tube is held in place by insulating cement. Inside the porcelain tube the gap units are placed. Each gap unit consists of two punched metal hats of special alloy. The crowns of these hats are turned so they face each other, and both crowns are knurled. Between the rims of the two metal hats there is a short porcelain tube which holds the crowns of the

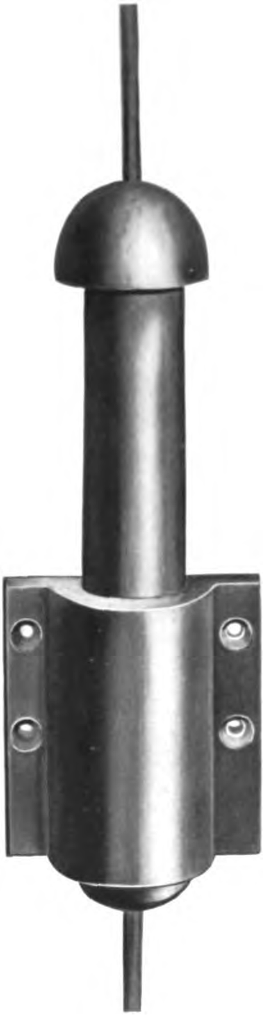

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FIG. 2.—EXTERIOR VIEW OF ARRESTER.

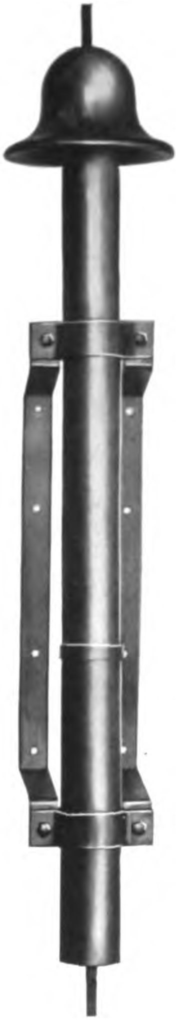

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FIG. 6.—EXTERIOR VIEW OF HIGH POTENTIAL ARRESTER—10,000 VOLTS.

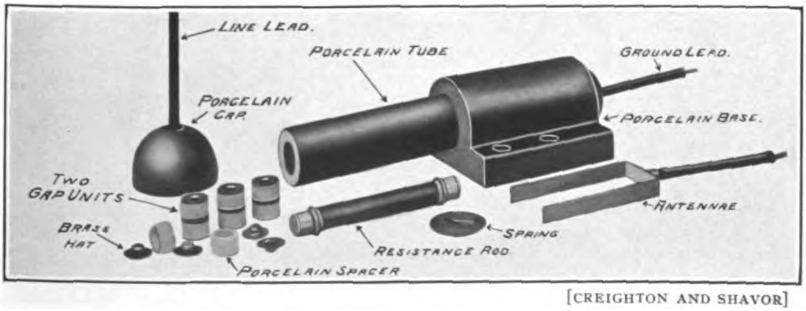

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FIG. 3.—DISASSEMBLED VIEW OF ARRESTER.

metal hats about 1/32 in. (0.8 mm.) apart. These gap units are stacked one on top of the other inside the porcelain tube between the arms of the antennæ. On top of the gap units is placed a resistance rod of low ohmic value. The gap units and resistance rods fill the long porcelain tube. On top of the resistance rod a spring contact is made, and a porcelain cap is fitted over the end of the tube and cemented there. Through the porcelain cap the connecting wire projects. The ground connection is a wire which passes through the bottom of the base and is connected to the antennæ as well as the lower gap unit. The arrester is hermetically sealed so that no dust, dirt, or moisture can get inside.

Characteristics of the Arrester

The arrester required thousands of actual tests to determine its characteristics and choose the proper values of the factors involved. Some idea of this work and the methods is given at the end of this paper in a condensed form. At the present time it is desired only to review its distinctive characteristics, such as the series resistance, gap units. spark potential, short circuit conditions, endurance to rapid strokes, life of the arrester, tests of arresters for protecting transformers, etc.

Series Resistance. Some years ago a complete development was made on a multigap arrester in which the series resistance was shunted by gaps. This feature has proven of very great value for heavy discharges of lightning. There is no possible doubt that when a heavy discharge of lightning is thrown on the arrester, the ohmic drop of potential in a series resistance is objectionable. Therefore, it is necessary to justify the abandonment of this valuable principle in one form of this new arrester.

Compression chamber arresters are not designed for the protection of valuable station apparatus where the maximum possible protective value is essential to the continuity of service. But the arrester is designed especially to protect small transformers where the cost is comparatively slight. The arrester, therefore, must have a cost that is compatible with the cost of the small transformer. At the same time the arrester must maintain a very high degree of protection. Due to the high factor of safety in the insulation in the design of distribution transformers, this is made possible in the cheap arrester. Due to the effect of the antennæ in this arrester, which will be described later, it is possible to use more than the usual number of gaps in series. In consequence, the resistance in series with the gaps may be kept at a very low value. The average value of this resistance is 23 ohms. The discharge current to ground per phase will be equal to the lightning potential divided by 23 ohms.

The next question is, what is the limit of the safe value of lightning potential which can be applied to the transformer? The high factor of safety, *i.e.*, five given to the insulator of these transformers, as compared to the usual factor of 2.5, is the element which gives justification, as will be shown, to the use of series resistance. All these transformers are tested for one minute to a potential of 10,000 volts. Therefore, momentarily, they will stand a very much higher potential. This higher value for the momentary application is unknown, but 15,000 volts is surely a safe value to assume. With a lightning stroke of 15,000 volts at the terminal of the arrester, the discharge rate of the arrester will be 15,000 divided by 23, which is approximately 650 amperes. In other words, this arrester applied to this particular transformer has a discharge rate of 650 amperes before the lightning potential reaches a dangerous zone. From both theory and practice, this value seems to be sufficient. In the aluminum arrester the design is made such as to give this discharge rate of current at double potential.

The Antennæ. Turning next to the subject of spark potential, we have known for years that an antenna placed near a multigap arrester always reduces this spark potential. In fact, any ground surface in the neighborhood of the arrester will produce this effect. It was one of the difficulties we had to contend with in the design. An arrester designed to be placed very near a connecting wall would sometimes have such a low spark potential as to require more gaps placed in series. On account of the particular conditions of the design of the standard multigap arrester, it was not found feasible to utilize the antennæ. However, with the form of insulation in the compression chamber arrester the antennæ can be easily applied.

In theory the antennæ make the arrester more sensitive by increasing the electrostatic capacity of each electrode to ground, while the electrostatic capacity to the adjacent electrodes remains constant. This theory was given by Dr. Steinmetz in 1906.

The use of the antennæ gives, first of all, uniformity in the spark potential regardless of the surroundings. In the next place the use of the antennæ reduces the spark potential of the series of gaps used in this arrester, to exactly one-half of the potential without the antennæ. This permits the use of twice as many gaps as would otherwise be possible. Each gap has the function of extinguishing a certain potential applied to it. Therefore, when the number of gaps is doubled, the arc-extinguishing power of the arrester is greatly magnified.

Characteristics of the Gap Unit. Each gap is enclosed in a sealed chamber, and any expansion of gases in that chamber will cause an increase in pressure, which, as is well known, tends to extinguish an arc. Furthermore the porcelain tube which encloses the gap has its cooling surface in close proximity to the arc. The cooling effect of this porcelain surface is demonstrated by the grayish deposit which takes place after the arrester has discharged many thousands of times.

The spark potential of this arrester can be set at any desired value. The most desirable value seems to be about 0.7 of the value of the potential at which the transformer insulation is tested. This spark potential is apparently safe for the transformer, and at the same time it is sufficiently far above the potential of the recurring type of internal surges as to make the arrester safe from destruction by these surges. In other words the arrester is designed for lightning and only such internal surges as reach a dangerously high value. For the general protection against internal surges on a 2300-volt system it is better to trust to one aluminum arrester situated in a station. The aluminum arrester can have a spark potential as low as one-fourth and even one-fifth the tested potential of the transformers and still be safely operated on 2300 volts. By following this practice it will be seen that the compression chamber arrester will be called on to carry successive discharges very rarely. As to successive lightning discharges, the compression chamber arrester is designed sufficiently strong to withstand many more successive discharges than ever take place. This is explained later.

Short-Circuit Conditions. It is therefore necessary to take precautions only to arrange to clear the line of the arrester in case some extraordinary condition shall arise, such as a direct stroke or a cross with some high-tension circuit, or any unforeseen condition which produces a continuous discharge in the arrester. This is accomplished by the breaking of the porcelain tube from the heat given out by the resistance rod. Each resistance rod has a certain capacity for absorbing heat. Since the amount of energy concentrated in a resistance rod is very great as compared with its radiating surface, the rod will heat so rapidly that one needs hardly to consider the radiation as a factor in a lightning arrester rod. If the discharges are practically continuous the rod will quickly heat to incandescence, and will crack off the tube. The cap will then dangle from the wire but the line will be free of short circuits. Inspection then, of the lightning arrester will consist simply in visual observation from the bottom of the pole. Since the resistance rod is the weakest spot in the arrester, one may conclude that if the arrester is not broken, it is in good condition. Still further proof of this will be given later.

Endurance of the Arrester to Withstand Rapid Strokes. In order to determine the strength of the arrester to withstand rapid successive discharges, an arrester had applied at its terminals, 170 per cent of its dynamic potential. The discharges were made through the gaps by means of an induction coil. This induction coil was operated from a make and break contact which made thirty strokes per second. An oscillograph was placed in series with the arrester in order to measure the number of strokes applied to it. Forty-five strokes were applied during 1.5 seconds without causing any damage to the arrester. The greatest known number of successive strokes from lightning in a second is shown by some photographs. This number is only a fraction of the number applied to the arrester. Tests made in connection with Mr. J. A. Clay on the Animas Water Power Company's line, 1907, showed that nearly every stroke of lightning consisted of a succession of discharges, and that the usual number lay in the range of 3 to 9. Sometimes these are distributed over an entire second, but usually they occupied only a very small fraction of a second. As already stated, the limit of the number of discharges is set by the heating of the resistance rod. If the successive discharges are spread out with several seconds between, then the radiation from the resistance rod is sufficient to give the arrester a very long life for such discharges. The actual limit for one of these rods is 50,000 joules, which corresponds to the normal dynamic discharge current for $\frac{1}{4}$ sec. on one type of resistance rod.

Life of the Arrester. In order to determine whether it would be desirable to leave the arrester open at the top so that the gap units could be replaced after they had worn out, a number of life runs were made on the 2300-volt compression chamber arrester to determine how frequently such a change would need to be made. The result showed that the life of the arrester was so great that it was entirely unnecessary to make any provisions for changing the gaps. For example, discharges were applied to the arrester with intervals of one minute between. These discharges were continued up to 9000. The arrester was tested with the oscillograph at about every 2000 discharges to determine its condition, and the spark potential was taken. Both these tests showed that the arrester was at all times of the run in as good a condition as at the beginning. The rectifying power of the gaps was the same, and the spark potential of the arrester, even after the 9000 discharges, remained constant. In other words, these discharges did not burn away sufficient metal from the surface of the electrodes to increase the spark potential, although a dynamic potential of 70 per cent above normal was applied to the arrester. The insulation between electrodes, measured by a "megger," was far above 2000 megohms,—practically infinite. When a gap unit was split open a considerable deposit of soft grayish material was found on the walls of the chamber and around the gap, but this material was non-conducting.

TESTS OF ARRESTERS PROTECTING TRANSFORMERS

These tests were made in the laboratory with artificial lightning. An explanation is due at the outset that one cannot reproduce in the laboratory all the forms of lightning that occur from the elements, yet certain forms of laboratory tests along this line of endeavor are not to be despised. In this case we produced an artificial lightning stroke at the terminals of the transformer, of sufficient strength to puncture the insulation between primary and secondary. All we can say of this lightning stroke is that it was of unusual strength as compared to the ones which ordinarily occur on a 2300-volt line. A large number of transformers, both new and old, were available for testing the protective value of the lightning arrester.

The following set of tests is illustrative of the statements regarding the protective value of the arrester. A 2300-volt transformer was placed in parallel with a lightning arrester and subjected to the discharges of artificial lightning. Three thousand discharges were made and no damage occurred to the transformer. The arrester was then removed and the transformer punctured between primary and secondary on the very first discharge. The question next arose whether the transformer had not been damaged by the 3000 discharges, so another transformer was placed in circuit without the lightning arrester.

The first discharge of artificial lightning punctured the transformer between primary and secondary. Again another transformer with the same insulation was placed in parallel with a lightning arrester and subjected to successive discharges. After 3500 discharges had passed, it was decided that no damage could be done to the transformer while protected by the arrester and the arrester was removed. Again, as before, on the very first discharge without protection, the transformer failed.

These tests tell us that the lightning arrester will give protection against strokes that will damage the transformer. They do not tell us that the arrester will give protection against all strokes, since it is conceivable that a lightning stroke may have a rate of discharge such that an ohmic drop across the resistance rod might be sufficient to give a dangerous potential across the terminals of the transformer. On the other hand, to offset this possibility, there is always a limited spark potential around the bushing on the transformer and it is only necessary to make this spark potential somewhat lower than the spark potential between primary and secondary in order to minimize the dangers of even a direct stroke.

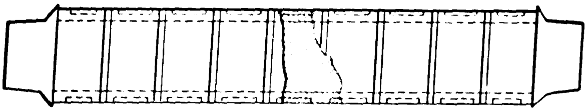

FIG. 4.—RESISTANCE ROD, ASSEMBLED WITH BRASS RINGS.

PROTECTION AGAINST OHMIC DROP ALONG RESISTANCE RODS OF THE ARRESTER BY-PASSING THE ROD

It is conceded that for this 2300-volt arrester the ohmic resistance in series with the arrester introduces an undesirable element when the current in the lightning stroke exceeds 650 amperes. Dr. Steinmetz has shown that the discharge of a surge traveling along a line cannot exceed a certain value of current per volt due to the inherent inductance of the transmission line. These calculations give a considerable confidence that the current in the lightning arrester circuit scarcely ever approach 600 amperes. Long experience with the aluminum arrester with its 600 amperes discharge rate at double potential also shows that the lightning discharge which exceeds this value is exceedingly rare. These elements taken together with the desire to keep the price of the arrester within a value compatible with the price of a small transformer and the value of uninterrupted service, makes us adopt the design in the form shown in this paper.

In order to meet the conditions of installation between the small pole transformer and the important apparatus in the power house, an intermediate solution of the problem is made by a compromise between the standard graded shunt resistance type and the arrester just described. The resistance rod is by-passed by a set of multigaps consisting of brass rings placed around the rod. There is a small gap between adjacent rings. See Fig. 4.

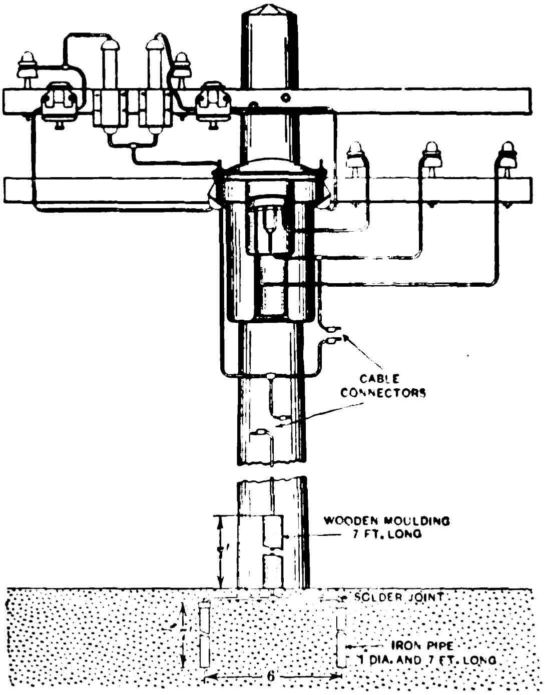

Fig. 5—Apparatus and Connections for Lightning Protection of Individual Transformers.

Recommendations for the Installation of Arresters for Protecting Distribution Transformers

It seems desirable to include in this paper recommendations for the installation of the arresters. There are some features which are of primary importance, and others which have to be varied somewhat according to the local conditions. Fig. 5 shows the installation of lightning arresters and 2300-volt transformer on a pole for a non-grounded neutral circuit. The relative location of arresters and transformers may be varied to suit the local conditions. Where a grounded neutral circuit is used only one of these arresters is necessary, the arrester being connected directly across the transformer, and a small extra gap added between the neutral wire and the wire which runs down the pole to earth. The assumption is made in this case that the neutral wire is grounded only at the substation. Again, some difference will be found in the installation according to whether the practice of grounding the secondary is followed or not. The figure shows the connection where the secondary is grounded. If the conditions are the contrary, it is not intended to recommend the grounding of the secondary at the transformer in the manner shown. In fact, the secondary could in any case be grounded through a single unit gap. This gap is made up in the same way as the arrester already described, but it is not illustrated in this paper. Recommendations are reduced to a very brief form in the following list:

1. Install lightning arresters on the same pole on which the transformer is placed.

2. Install an arrester at every transformer.

3. Make the connections from a line wire through the arrester to the transformer case, as short and direct as possible.

4. In making the connections between the lightning arrester and the line, have the point of contact not vertically above the wooden cross arm or any connecting parts in the neighborhood. The idea in this precaution is to prevent trouble in the extreme case of damage to the arrester. For a continuous discharge in the arrester, the resistance rod will finally heat and crack the porcelain. The cap will break loose and will dangle free of any possible persistent short circuit.

5. Connect the arresters in general on the line side of the transformer fuses.

6. Ground the transformer case by means of an iron, or copper wire. Since the lightning arrester is grounded onto the case, the drop of potential down the pole along the ground wire is of less consequence than in the former practise when the case was not grounded. Therefore, cheap telegraph wire can be used for the connection between the transformer case and the pipe-earth.

7. If bare wire is used, it is recommended in some cases that a wooden strip be placed over the ground wire for a distance of about 7 ft. (2.1 m.) from the ground up. This addition is used to avoid danger of shock from the ground wire when a cross occurs between a primary and the ground. A cross continued

long enough sometimes dries out the earth connection. There are many cases and places where this is not necessary. Insulated wire may be substituted for the wooden strip.

8. At some point part way up the pole place a clasp connector. This connector is to be opened by the lineman and the ends bent back, when he climbs the pole, in order to insulate the transformer from ground by means of the intervening wood of the pole.

9. If the practise is already followed of grounding the secondary, then use either a small gap between the secondary and ground wire of the arrester or ground the case of the transformer directly on to the secondary through a connector. This connector is also to be opened by the lineman as a matter of safety when he is working around the transformer.

10. For the earth connection in the usual soil, drive a one-in. (2.5 cm.) pipe in to a depth of six to nine ft. (1.8 to 2.7 m.) A shallow hole should be scooped out at the surface of the ground and the top of the pipe driven below the surface. In unusual conditions of very dry, sandy, or gravelly soil, two ground pipes six ft. (1.8 m.) apart, may be desirable. If the ground wire is protected from corrosion it can be carried directly to each of the pipes. A soldered joint on the pipe is desirable.

11. The earth should be scooped out several inches below the soldered joint and several double handfuls of salt placed in this basin. It is desirable to add some water at the same time. The earth can then be filled in to the level.

Due to varying conditions and tastes, the method of making the earth connection and the materials to be used can be left somewhat to the discretion of the one making the installation.

The object is to have a pipe penetrate into the earth at some convenient distance greater than six ft. (1.8 m.), to have a connection between the grounding wire and the pipe earth which will not be corroded or pulled off, leaving a large gap, and to keep the salt solution away from the soldered joint as much as possible so as to prevent local corrosion at the joint.

As a suggestion, it might be well to use No. 10 or No. 12 insulated wire from each pipe earth to the lower joint of the connector which is placed as a break in the vertical wire, and use iron wire from there up, the iron wire being stapled to the pole.

It is *very important* to note in connection with this practise, which may seem less rigid in regard to grounding than has previously been recommended, that the conditions are different due to the connection of the lightning arrester to the transformer case.

The drop of potential down the connecting wire on the pole and through the resistance of the earth connection is thereby rendered of comparatively little importance.

In regard to the cost of the materials for this method of grounding, the galvanized iron telegraph wire, from the top of the pole to the pipe earth, will cost about 6 cents. Costs on plain iron pipe one in. (2.5 cm.) in diameter is about 4 cents per ft. Therefore, a pipe 8 ft. (2.4 m.) long would have a cost of 32 cents. The galvanized iron pipes cost one cent more per foot.

It is difficult to see the need of using galvanized iron pipe because the plain iron pipe will last for ten years at least.

By following the practise recommended above, the cost of installation of the lightning arrester, including the cost of the ground wire earth pipes, all is reduced to a small fraction of the cost that was formerly found necessary.

SOME DETAILS IN THE DEVELOPMENT OF THE LIGHTNING ARRESTER

Compression Chamber Arrester for Higher Potentials. There is less demand for an arrester for potentials above 4000 volts grounded neutral. The same design is applicable, however, to the higher potentials. In certain isolated cases this arrester is applicable. Fig. 6 shows the form of a compression chamber arrester for 10,000-volt circuits.

Some Miscellaneous Notes and Tests. In former years it was thought that the design of a lightning arrester required a considerable degree of imagination. Little twists, points, capacities, and fantastic contrivances were placed in the path of the lightning to confine it, and while it was all mixed up in its directions it was to be slid off harmlessly to the ground. In reality the design of a lightning arrester is a relatively prosaic affair. Nothing is left to chance. A test can be devised to gain some knowledge of every factor.

To give full details of the experimental determination of the factors involved in an arrester would, we fear, be of little interest to the members of the Institute. A brief statement of each step may be of interest to indicate the methods and care that are involved. This brief account follows:

Tests were made to determine

1. If gaps enclosed by hollow cylindrical spacers, which determine a certain gap length between electrodes, will extinguish the dynamic arc without destroying the enclosing spacer.

Tests were made using hollow cylindrical spacers of different lengths and different inside diameters. Tests proved the arrangement to be practical and efficient.

2. The minimum gap length permissible to prevent bridging of the gaps by molten metal thrown from the arc crater during discharge, under conditions noted in (1). (Standard lightning arrester electrode metal used in test.)

3. The possibility of using punched sheet metal electrodes versus solid metal electrodes of like material for efficiency and durability.

4. If discharge faces on the electrodes should be smooth or knurled.

5. The material to be used for spacers.

Many materials were tried among which were fiber (treated and untreated), hard rubber, glass and porcelain.

6. Form and size of discharge face of the electrodes.

7. Inside diameter of porcelain spacer to insure no assistance to dynamic arc in holding across the gap.

8. Length of porcelain spacer to obviate any possibility of deposit from material thrown off by the arc to form a conducting surface from one electrode to the other thereby short circuiting the gap.

The length was determined at 17/32 in. (5.5mm.) 9000 consecutive discharges on a 2300-volt circuit, using sealed gap units, failed to render the surface of the spacer conductive.

9. Leakage factor of porcelain spacer 17/32 in. (5.5 mm.) long.

The leakage factor for this spacer as found by test on a 60-cycle circuit is 6,350 volts effective.

10. The value of resistance to be used in series with the gaps on a 2300-volt circuit.

A number of tests were made by varying the number of gaps from two to six, also varying the resistance from ten to one hundred ohms.

A test was run using a minimum number of gaps (2) and a minimum amount of resistance (10 ohms).

A typical test is shown by the use of three gaps with a 23 ohm resistance rod in series, all of which were enclosed in a porcelain tube. The arrester was sparked over by the use of a static machine.

At the end of 100 discharges taken at intervals of five seconds the temperature rise of the tube above the air was 23 degrees cent. No damage was done to the arrester and no fuses were blown.

11. The effect of water in the containing tube on the operation of the arrester.

The tube was supported in a vertical position with the line end (top) open and only a small hole in the opposite, or ground end. The arrester was then connected across the 2300-volt circuit using one strand of five-mil boker wire for a series fuse. The test was started using one drop of water every ten seconds and run for 70 minutes.

Most of the water was evaporated.

Boker wire changed for a 20 ampere fuse. Flow of water increased to one drop every 7 seconds, the arrester being subjected to a static discharge every two minutes. Tests run 45 minutes; operation of the arrester was normal.

Flow of water increased to 85 drops per minute and run for 15 minutes. No trouble developed.

Flow of water increased to a tiny stream. Some steam given off. No fuses blown. Temperature of the tube 28 degrees cent above the air.

Flow of water increased to one pint per minute. No trouble developed. Temperature of tube decreased to 15 degrees cent above the air. No fuses blown.

Several porcelain spacers were soaked in water for two days. The effect on spark potential of the gap using these spacers, was not material.

12. The rectifying power of various metals and alloys in form of sheet metal electrodes, as now used in the arresters, and also in form of our standard lightning arrester cylinders.

The amount of zinc volatilized during the life of the sheet metal electrodes is minute. Measurements were taken before and after 500 discharges, at 100 ampere discharge rate, applied to the gaps. The result was a gain of two milligrams in one electrode and a loss of 3 milligrams in a total of three others. This amount was too small to be accurately measured with the available balances.

13. Many tests were made which can be mentioned only in a general way. Among them were:

Tests to determine the length, size and form of the antennæ.

Tests to determine the equivalent-needle-gap under various conditions, by use of the static machine; Tesla coil; induction coil; 60 cycles; quick break; direct impulse and lightning generator.

Tests to determine per cent surge; per cent spark potential; etc.

Many oscillograms have been taken at critical points in different tests and on endurance runs.

14. Curves were run to show the following:

a. Minimum length of antenna to be used. Minimum length of antenna to give the maximum capacity effect was determined at 87.5 per cent of the total length of number of gaps used.

b. Spark over potential of containing tube. Tube both wet and dry. Test made only to limits of 10,000-volt arrester (50 gaps). Antenna at 87.5 per cent of length of gaps safe. Spark over potential to support when dry 100,000 volts. Spark over potential to support when wet 80,000 volts. Factor of safety is 8.

c. Spark potential of gaps for high voltage arresters; gaps varied; antenna 87.5 per cent total length of gaps. Fifty gaps spark over at 21,000 volts at 60 cycles.

d. Antenna surrounding containing tube versus 1/2 in. (1.2 cm.) strips on opposite sides. Antenna surrounding tube requires less spark potential than ½ in. (1.2 cm.) strips. (6.4 per cent.) less for 4 gaps to 6.8 per cent less for 50 gaps.

e. Spark potential using antennæ versus no antennæ. Removing the antennæ raises the spark potential 100 per cent.

f. Spark potential, with antennæ, using single tube versus two tubes in series. Using two tubes in series raises the spark potential about 20 per cent. Therefore, all the gaps for one leg of an arrester should be assembled in one tube if at all possible to so do.

g. Spark potential tests: Antennæ connected to grounded end versus antennæ connected to line end of arrester. The antennæ connected to the line end of the arrester raises the spark potential of the arrester about 10 per cent for low voltages and from 15 to 20 per cent for higher voltages (10,000-volt arrester.)

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HUMAN ACCURACY: MULTI-RECORDER FOR LIGHTNING PHENOMENA AND SWITCHING

BY E. E. F. CREIGHTON, H. E. NICHOLS AND P. E. HOSEGOOD

The object of this paper is to describe a new instrument which will record the time to the second of a phenomenon of any kind that can be made to close an electrical contact. Besides recording whether a phenomenon is starting or stopping, a printed record is made of the day of the week, a.m. or p.m., the hour, minute, and second. The highest number of records put on a sheet by a single one of these instruments so far is thirty. The instrument is capable of recording a movement of all of its pencils or type wheels simultaneously, or the movement of any lesser number. Every record shows the position of every type wheel whether it moves or not. The instrument records only to the nearest second but in case of successive discharges during a single second their relative precedence is noted by giving them successive prints of the same second. In this manner the recorder will split a second into about four parts. The manner of operation will be described later.

The field for this device in theoretical and practical investigations on transient electrical phenomena is immediately evident to those interested in this subject. The field in practical applications of electricity are not so evident. It is thought, however, that this instrument falls in that class of devices which has no apparent demand before it appears but becomes somewhat a necessity afterwards.

As electrical distribution in lighting, motive power, and railways becomes more standardized and conventionalized there is an increasing demand for higher reliability from employees and an imperative need of knowing what the apparatus is doing, especially during periods when accidents are taking place. So long as a plant or railway runs along smoothly, knowledge of simple routine duties is sufficient. During times of trouble there is an immediate demand for the highest knowledge and quick accurate judgment. The man with such knowledge and judgment has demands on his time which put him out of reach when he is most needed at the scene of trouble. Grant that he has chosen his helpers well—that they are honest, loyal, and conscientious—still there is no guarantee that they will be able to meet the situation. There enters a psychological factor. What will a man do under stress and excitement? His conscientiousness may be the factor that inhibits quick and accurate action. After an accident to a power plant, how is an engineer to know whether the trouble was due to faulty manipulation of the switches or some unavoidable failures of the insulation? Too often a localized trouble is made into a general interruption by a mistaken operation of a switch. How can the reliable operators be picked out? Surely not by their good characteristics under normal conditions of emotion.

Several personal experiences will be given to illustrate the fallibility of observation, especially during periods of mental or nervous stress, and the effects that the characteristics of the individual have in noting their observations.

An example of disagreement in noting simple phenomena occurred in Colorado, 1907. Mr. F. W. Peek, Jr., and one of the writers were making studies of lightning effects in conjunction with Mr. John Clay, superintendent of the Animas Power & Water Co. A heavy lightning stroke started noisy arcs between some terminals and the ceiling, six feet above. There were two of these arcs, making twelve feet total length and absorbing the entire power of the plant. When the trouble started Mr. Clay was outside the building, Mr. Peek was in the third floor of the high tension gallery, and one of the writers was on the main, ground floor. When the arc was finally put out by the hand manipulation of a faulty oil switch located on the third floor of the high-tension gallery Mr. Clay and the writer were in the gallery, and Mr. Peek was on the floor. Later, we compared notes of the sequence of events, such as the lightning stroke, the starting of the arc, the precipitate exit from the station of several linemen, the entrance of Mr. Clay, the discharge of lightning arresters, the opening of secondary switches and our own movements, up to the time the faulty high-tension switch was opened by hand manipulation. They made three distinct stories, each man positive of his impressions. There was no way of getting at the real truth. We feel we are trained observers, so surely men in power houses with less training could scarcely be censured for wrong impressions. It was extremely important to all of us that the arc should be extinguished immediately so as not to damage the building. The nervous tension was, therefore, unusually strong, although it could scarcely be said we were excited.

This illustration calls to mind one recently used by a most eminent practical psychologist in a lecture on the psychology of *evidence*. A professor of law was giving a lecture to third year students in law, when in the midst of the lecture two students got to quarrelling. Their voices rose in altercation and they finally came to blows. It was necessary finally to eject them from the class room. The situation was so important that the professor had each student write down immediately what he had seen and heard. These sheets of written evidence were collected and tabulations were made of their accuracy. The quarrel had been prearranged, and thoroughly rehearsed beforehand so that the professor in charge had a record of every word spoken and of every act. In this case the absolute truth was known. This brought a remarkable condition to light. A majority of these men who were being trained for the law, were unable to give accurate evidence of what they had seen and heard. This inaccuracy is exhibited not merely in the matters of which the observer did not feel quite sure, but just as often in the details of which he felt quite sure.

In some studies that were being made of multigap lightning arresters about six years ago one of the engineers from the lightning arrester laboratory was stationed for purposes of study in a power house where two high-tension lines entered from one side. Along this wall were twelve compartments for the different phases of lightning arresters. This occupied the entire length of the room. A person stationed on the opposite side of the room could have all twelve compartments within the range of vision. During storms four compartments at each end of the room had arresters in them which were active. We received reports directly from the laboratory engineer which were noteworthy for their lack of detail. Through the manager of the plant we received details from discharges on the arrester as taken by one of his best operators. In spite of pressure brought to bear on the laboratory engineer, he could be positive of discharges only over the arrester at which he had been looking, whereas, the station operator would describe minutely that discharges had passed over three or four of the different legs of the lightning arrester widely separated and would designate which phases, and which lightning arresters. Later we had occasion to look into the matter and we thought at first there was a possibility that this young man had unusual keenness of vision, and we feel quite sure he thought he saw what he wrote down. There was no attempt at deception. It was simply a matter of an imaginative mind. He had naturally an observing disposition and after he had made a short trip through the hills with his gun he would always have interesting stories of incidents of the trip. On one of his trips one of us attended. We found from his descriptions to others afterwards that the incidents were correct but the matter was highly colored by his naturally expansive imagination in associating a simple incident with details which did not actually occur. So far as investigations on lightning were concerned his evidence was worse than none at all due to his peculiar characteristics of mind. His statements of lightning strokes and effects he had witnessed made interesting fiction but these statements could not be used as a basis of an engineering development.

In another case an operator, likewise, gave an exceedingly readable account of everything which took place in the station with records of the exact minutes of each incident even during times of stress and interruption. These records gave to the reader the impression of great accuracy. I found on questioning, however, that during these times of trouble he was occupied with telephoning, watching the lightning arresters and several various incidental things and that the records were written up some time subsequently. He thought he remembered the time intervals and could put them down accurately. In this case it was a matter purely of lack of training.

The importance of the psychological aspect of the efficiency of men under trying conditions is appreciated by operating men, as evidenced by the fact that Professor Münsterberg has been asked to develop methods of examination for car motormen which will determine their reliability of action and weakness of judgment in avoiding accidents in their work. In a conference of railway men lasting two days it developed that some of the most reliable men under ordinary conditions, with many years of experience and with trained judgment, have more accidents per year than even some of the raw recruits. There seems to be something that inhibits normal operation of the mind when suddenly called on to decide whether to apply the brakes, apply the reversal, or increase the speed.

A valuable recording device was described at the annual meeting of the Institute last year. This device recorded the exact position of the synchroscope when generators were paralleled. It was reported that at first the men were very disgruntled at having an automatic apparatus used to check up their best endeavors. Later, however, this feeling passed away.

If one is to really run a business nothing should be left to chance or haphazard judgment. This statement involves the fundamental law of success in running any business or in filling any position of responsibility. Know what is going on. It is a duty. In any standardized line of activity, if something goes wrong there is no excuse for the engineer. His profession is to know and to foresee. He is the guardian of the greatest proportion of the affairs of material things in the world. Since he has made a success of these affairs he is constantly being called on to extend his methods of exactitude to human affairs. Although there is no excuse there may be an explanation for a calamity. There is no balm, however, to the unfortunate investor and stockholder in an explanation. It may be desirable to run a certain degree of risk in the possible loss of apparatus and income, but this risk must be run with the full understanding that it is more than counterbalanced by the interest on the investment that would otherwise be needed. Incidentally, a sinking fund should be provided to cover this risk the same as to cover interest on an investment.

The means of obtaining knowledge by the engineer is in no way of the nature of espionage. The case of the synchroscope, previously cited, is a good illustration. To avoid an interruption of supply of electricity to hundreds of thousands of users in Chicago, to say nothing of the cost of damage to apparatus, it is necessary to have a spare machine not only at the same frequency and potential as the other machines before closing the generator switch which connects it to the system, but it must also be in the same phase relation. On the part of the switchboard attendant there must be not only certainty of the position of the needle of the synchroscope but there must be knowledge of the time of mechanical motion of the switch and the lead or lag due to the personal equation. The wisest man in the world must have some device or method in order to determine his personal equation. Even the wisest man may have an unreliable personal equation for use in synchronizing alternators. It is the engineer's affair to know this, to utilize the mental wisdom in its place, and also to train the man with manipulating ability. The engineers who devised the recording synchroscope state that it gave not only to the one responsible for the proper operation of the plant a reliable record but it gave also to the attendant a means of finding himself and of improving his work, which was previously impossible.

A switchboard room is the brain of the electric system. Improper switching is a curable electric insanity. Great losses have been caused by mistakes in switching and there has been no evidence left to indicate the mistake and no possibility of justly placing the blame. In such cases a disconcerting feature is the impossibility of properly changing the personnel of the station force so as to avoid a repetition of the same blunder under similar conditions of nervous strain. Aside from the loss of apparatus, personal injury has sometimes resulted from a mistake in switching. From a legal standpoint it is not infrequently important to have evidence to show that damage was not due to improper switching. In one instance that comes to mind eight linemen were injured and one killed while stringing up a broken line. At some distance away there was a lightning storm. It was difficult to decide whether the fatal charge of electricity was due to the lightning or to a mistake in switching at one of the stations or to some local carelessness.

Where so much depends on a knowledge of switch operations it would seem that any device which makes an accurate record would give not only a good insurance against repeated acts of inability and carelessness but would also be worth while in the training of reliability in men and in furnishing valuable evidence of conditions that any business demands.

Two experiences out of many are chosen for further illustrations. In charging an aluminum lightning arrester a very good allround switchboard attendant decided to do his work thoroughly. He was instructed several times to charge about ten seconds but he failed to catch the desirability of any limitation; consequently after some damage had taken place an examination was made of the record of the discharge recorder which showed that the wear on the plates of the aluminum cells during one year was equivalent to forty years of normal service. Doing the work thoroughly meant, to him, charging the arrester for seven minutes instead of ten seconds.

In the process of manufacture of some insulating material in the factory, there were several successive steps which required exact intervals of application of electrical current, potential and heat. A man was trained to carry on this work. After he undertook the tasks independently he was checked a number of times and found reliable. From time to time certain unmistakable variations in the final product were found. The workman could give no explanation. He claimed he had conscientiously given the proper time to each application. There were good reasons for not doubting his honesty. Finally, however, it was decided to go to considerable expense to put in automatic recording devices. When occasional errors as great as fifty to one hundred per cent were subsequently found the workman was as greatly surprised as any of the rest of us. He had, apparently, occasional lapses or off-days. With the aid of the automatic recording instruments he was able to correct his lapses. The situation is now satisfactory to every one concerned.

Aside from the saving of expensive errors, the multi-recorder will have a use in diagnosing the source and growth of trouble on an electrical system. Events often follow each other in too rapid succession to be noted. Frequently an operator is not in a position to note what happens. Since the multi-recorder is more than twice as rapid in its operation as an oil switch it can follow the succession of events. Time element relays can be checked to the nearest second at every operation. Durations of accidental short circuit can be recorded. In some cases this will be of great value in forming an estimate of the possible damage that may have been done to the wires of a power line.

The multi-recorder will record when a line or feeder is alive, when it was energized, and from which end it was energized initially. This is accomplished by the use of two type-wheels or pencils. Assuming the use of the printing type, one type-wheel is connected to a contact on the feeder switch and the other is connected to a contact on an electrostatic couple which is energized by the line or feeder. If the line or feeder is kept alive by induction or by an accidental cross with another circuit the multi-recorder will continue to record the letter " R ", after the feeder switch is opened.

Other uses of the recorder will sometimes be found about a station. A load dispatcher will find a number of uses for it. The connections of the multi-recorder can be used to make the load dispatcher's dummy switchboard automatic. More rapid switching can be carried on with accuracy. The exact conditions are always before him. A check record is made of every change. If desired, signals and responses can be recorded. The starting, synchronizing, and stopping of generators, the operation of ventilating motors, auxiliary apparatus, and even changes in a fire room, may be recorded.

Looking forward somewhat into the future, there is a growing demand for knowledge of the mental characteristics of the men who have functions made important by the reliability that is required under all conditions of surroundings and mental fatigue. No subtle psychological tests have to be imagined to determine these mental characteristics. What is needed is an actual switchboard not connected to the power circuit but used in conjunction with the multi-recorder. Tests are to be made when the mind of the man is fresh and clear after a night of rest, and again when it is fatigued at the end of a day of exhausting labor, and then again, perhaps, after "a night off with the boys." Imitations of various accidental conditions can be reproduced by explosions and pyrotechnics, and the accuracy and time of response to these impulses can be measured by the multi-recorder. To give these tests the seriousness and nervous strain attending actual operating conditions several other things are available. One factor might be certain mental stresses that can be caused by the presence of unusual and important witnesses. There are a number of things involving the element of surprise, which need not be reviewed here. It would be absurd to lay out rules for methods that have not yet been tried and tested. The end sought in each case will have everything to do with the choice of method and procedure.

It must be conceded that no set of tests will give absolutely positive proof that the results will indicate the choice of an unerring switchboard attendant, although they may come very near doing it. The methods will, however, eliminate immediately the applicants for such positions who have qualities of mind which entirely unfit them for the particular occupation of switching.

The choice, as the matter stands to-day, is left much to haphazard chance. The blunders which eliminate a man from the field of station attendant are very expensive. The case with which blunders can be covered up, and the importance of doing so to the man who makes them, leaves the engineer in charge in a vulnerable position. If one could learn even of all the blunders that resulted in nothing serious, a good basis would be formed on which to judge an attendant's abilities. The multi-recorder will give a great deal of this kind of information. With a full set of tabulated and type-written accidental conditions which can happen to an electric system taken in connection with the test switchboard referred to above, it is possible, after choosing men, to give them an extensive training in meeting promptly important situations which come infrequently to any particular man.

Application of the Multi-recorder to Theoretical Investigations. There are a number of important investigations on electrical circuits which require numerous accurate time records. One of the most important of these is the determination of the value of the overhead ground wire. Lightning storms move variably across and along transmission lines. Succeeding strokes produce punctures on spark-test papers which are superimposed and cause hopeless confusion in the interpretation of the results. One multi-recorder takes the place of thirty observers and it is more rapid and accurate. The salaries of thirty men for one day would pay a high rate of interest and depreciation on the multi-recorder for an entire year. With the necessary auxiliary apparatus the multi-recorder makes possible studies of lightning conditions which would, otherwise, be impracticable.

The Motorman Problem. The problem of testing the characteristics of a motorman is not very different from that of the one already outlined in relation to a switchboard attendant. Aside from the regret that attends a deplorable railway accident there is a legal aspect which materially affects the returns to the stockholders. How many motormen, reliable under normal conditions, lose their judgment, accuracy, and speed of action, at a moment when human lives are suddenly endangered by the movement of electric cars under their control? The problem is not far different from the one of training chauffeurs. A method of accurate tests is not difficult to devise. Briefly it requires the following elements: Moving pictures of specially arranged dangerous situations, fast and variable speeded vehicles suddenly appearing out of a side street and crossing or stopping on the track, confused pedestrians in various positions of danger, etc. For taking these pictures the camera is to be carried down the track in a light vehicle that can be suddenly stopped. Considerable attention must be paid to the rate of the moving film with the conditions of subsequent reproduction in mind. Let us assume that these records are complete.

The next step is to block up a street car in a car barn and connect the motor to sufficient inertia to equal that of the car. Place a screen a few feet in front of the motorman's vestibule and place back of this screen the moving picture machine. Gear the motor through a proper ratio to the moving picture machine. Put a recorder on the brakes, bell, the several positions of the controller, velocity meter, deceleration meter, and a contactor on the moving picture machine which closes the instant the dangerous condition appears. Put a motorman in the vestibule and as he runs his car down this eventful picture street measure automatically his judgment under various trying conditions, and his accuracy and speed of mental and physical response. If he passes the pictures through a dangerous situation before he can stop his motor and the picture machine, he has had an accident. Accidents which are absolutely unpreventable will be indicated by the impossibility of any motorman to respond to the impulse and stop his car in time. By the use of this outfit men can be trained to meet a situation promptly. To prevent over familiarity with the situations and the possibility of foreseeing a danger before it actually appears and prematurely preparing for it, fresh pictures of new situations can be supplied according to the need. No matter what flaws may be noted in this method, if it is applied with understanding and common sense it is possible, to say the very least, to weed out such applicants and men from the force as are inherently not adapted to this occupation.

To meet certain situations several seconds of afterthought are necessary. To reduce the time of response, most of these seconds of afterthought can be squeezed into forethought by experience. It is uneconomical to get this experience by maiming people. Everyone who has given it the least attention has noticed how actions become automatic. There is a world of illustration of this. Slip on the ice or a banana peel and a foot will shoot out quickly and recover the balance (usually) before conscious thought takes place. The fingers of a piano player and an operator of a typewriter, move automatically to the proper positions without conscious thought or effort. If we have a complicated electrical test to make, first imagine all the possible accidents that can take place and go through phantom actions for each case to train the senses to meet the situation promptly should it occur. This is storing up afterthought in the form of forethought ready for instant use. The same quick reaction can be cultivated in the mind of a motorman by the use of the apparatus described in the foregoing paragraphs.

THE MULTI-RECORDER.

Conditions existing in electrical work as outlined have suggested the necessity of a recording device which will make easily readable records of switching operations, lightning disturbances, arcing grounds, and in fact any phenomena mechanical or electrical which may be used to close an electrical contact.

The difficulties encountered in devising such a mechanism may not at first be apparent. The record after being made should appear comparatively simple. The first conception of what the record should be like was made by investigating the records made by other standard recording instruments such as the recording voltmeter, the discharge recorder, etc. In these recorders the record paper is continuously drawn through the machine, usually by a direct-connected clock mechanism. In many cases this would be a waste of paper and would also make a record which could not be easily read owing to the fact that a large amount of paper would have to be inspected before the desired indications of operation could be found. For this reason the idea of having the paper continuously moving through the instrument whether any operation was being recorded or not was abandoned and it was decided, if possible, to make the recorder move the paper in steps, the stepping to take place only when records of switching, etc., were made. It should be noted, then, that our problem is to record transitory phenomena. Many different schemes were considered as to the manner of producing a simple record. Of these, two were decided upon as being the most feasible and the easiest to read. The first consisted of a set of pencils equally spaced and bearing down on the record paper. These pencils are supported at the end of an arm extending outward from an operating armature. When anything to be recorded occurs, say closing or opening a switch, the pencil previously selected to record the operation of the switch, will move a short distance either to the right or left perpendicular to the direction of motion of the paper and will remain in this position as long as the switch remains open or closed. After the pencil has moved over, the paper is stepped forward a short distance and then remains at rest until a pencil is again moved by some recordable operation.

The second scheme was to provide type wheels in place of the pencils. Each wheel would have two characters cut in its rim and the operating switches would cause their corresponding wheels to be rotated so that the proper character would come in line to print. The characters chosen were *R* and *G* corresponding to red and green as used in switching. In addition to these letters successive numerals were used. The next consideration was the printing of the time. Owing to the fact that the paper was to be stepped only when something to be recorded took place, the record paper could not have the time previously printed upon it as in the case of the record papers used in recording voltmeters, etc. Therefore, some sort of a time indication must be made on the record paper at the same time any phenomena was recorded. As a result of investigations along this line it was decided to use a special time printing device which consisted of a set of wheels having type cut in their rims. The question then arose as to how accurately this device should print the time. In other words, if two records were made, say one second apart,

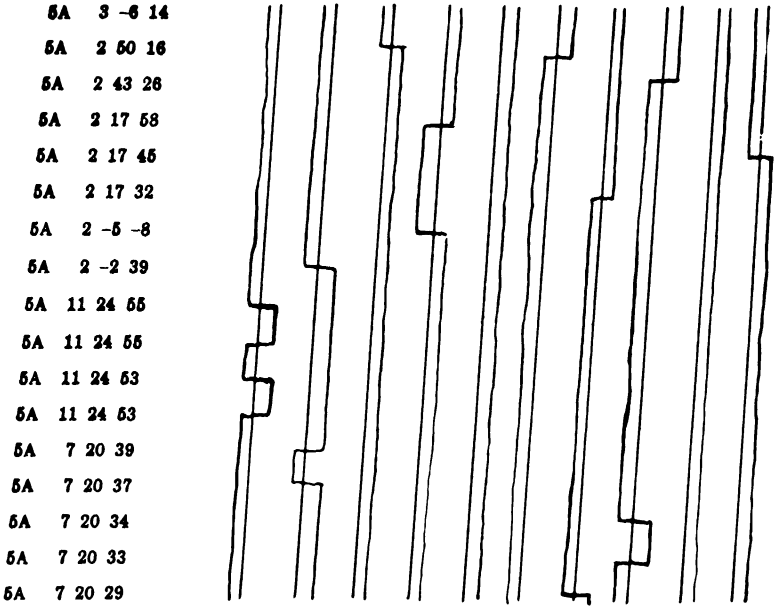
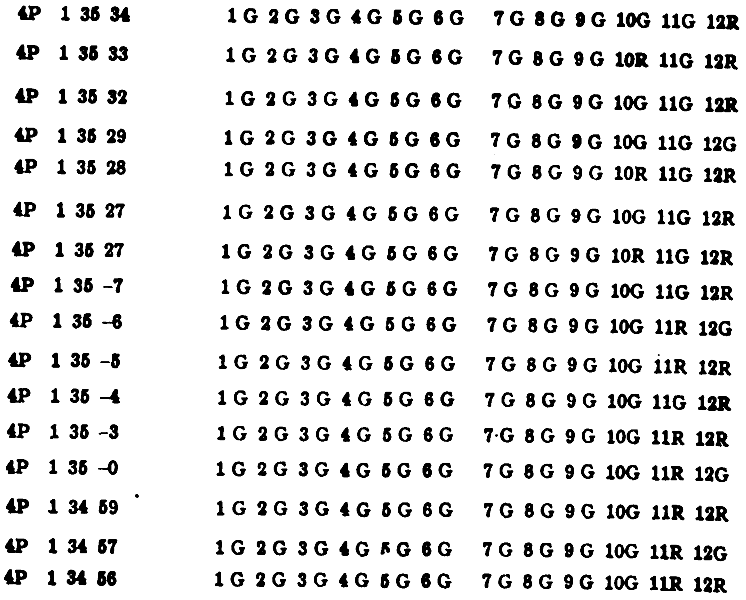


FIG. 1.—RECORD OF PENCIL TYPE MULTI-RECORDER.

would it be necessary to show that the difference in time between these two records was one second, or would it be sufficient to show the approximate time of day at which the records were made? Let us take an illustration to show one of the factors which influenced the final decision: On the system consisting of a number of feeders, it is not unusual that several switches will be opened in quick succession. It is impossible to tell where the trouble started, and which switch opened first. It is desirable to have the time element sufficiently small so as to separate such phenomena.



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4P 1 35 34    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11G 12R
4P 1 35 33    1G 2G 3G 4G 5G 6G   7G 8G 9G 10R 11G 12R
4P 1 35 32    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11G 12R
4P 1 35 29    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11G 12G
4P 1 35 28    1G 2G 3G 4G 5G 6G   7G 8G 9G 10R 11G 12R
4P 1 35 27    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11G 12R
4P 1 35 27    1G 2G 3G 4G 5G 6G   7G 8G 9G 10R 11G 12R
4P 1 35 -7    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11G 12R
4P 1 35 -6    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12G
4P 1 35 -5    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12R
4P 1 35 -4    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11G 12R
4P 1 35 -3    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12R
4P 1 35 -0    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12G
4P 1 34 59    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12R
4P 1 34 57    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12G
4P 1 34 56    1G 2G 3G 4G 5G 6G   7G 8G 9G 10G 11R 12R
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FIG. 2.—RECORD OF PRINTING MULTI-RECORDER.
Changes in the recorder are made in Nos. 10, 11 and 12.

The use of two disks in place of the hour and minute hand on the clock suggested themselves first, but in order to get an accurate time indication it would be necessary to have a very large disk, so large, in fact, as to be difficult to handle. Experiences with friction in such big wheels led us to believe that such a clock would be a poor time keeper, and therefore, we turned to an electrically driven clock, or a set of gear wheels. With this device it is possible to have one master clock run any number of machines, even to the extent of connecting different stations together, and in this way widen the scope of accurate record of the multi-recorder. The impulse for the electric clocks is received from a clock pendulum.

The principal parts of these multi-recorders are

1. A master clock.
2. Time-wheels for printing.
3. Record-wheels or pencils.
4. Printing mechanism consisting of a set of hammers which strike the row of type wheels.
5. The paper advancing mechanism.
6. Outside the machine are the contacts which move when phenomena occur which it is desired to record.

A problem of the multi-recorder involves the moving of 10 to 30 distinct recording devices, which can move singly, or all at once, without interfering either with each other or with the printing mechanism. The printing mechanism must be responsive to the movement of any one recording pencil or wheel, and to any number of them operating simultaneously. Furthermore, the printing hammer must not strike the time-wheels when they are moving from one second to the next. Since we desire to record the phenomenon when it takes place, it is evident that if a phenomenon occurs at the instant the master clock ticks, the time wheels must not move. Yet the second of time in the movement of the time-wheel must not be lost. These two conditions are fulfilled, when it is necessary, by delaying briefly the movement of the time-wheels. Definitely, what takes place if the phenomenon occurs at the end, say of the eighth second, is that the time-wheel will be delayed and the eighth second will be recorded; it requires $\frac{1}{6}$ second to make the record so that $1\frac{1}{6}$ seconds later the time-wheel moves up to 9 seconds. Five-sixths of a second afterwards the time-wheel moves up to 10 seconds on exact time.

Another problem connected with this device relates to the means of recording changes that are transitory in duration. The movement of an oil switch does not fall under this designation. The occurrence of the operation of a switch is transitory. but it has a duration of a second at least before it can be followed by another movement. In other words, the switch is either against the " open " contact or the " closed " contact in a definite manner.

The recording of a lightning stroke is something quite different. It comes and is over much sooner than any mechanical device can move. In many cases it is too quick even for an oscillograph to follow. On the other hand the problem takes a new form when the lightning strokes cause an accidental ground. Then the surges will be continual over a number of seconds or minutes. If the multi-recorder made a continuous record during all this time it would run out yards of paper uselessly.

There are other factors connected with the general phenomenon of surges such as large and small current, high and low potential surges, as well as the frequency and duration of the surges. These factors will be taken up later in a paper on " A New Discharge Recorder." For the present it suffices to state that the device which best meets most of the imposed conditions involves the use of a specially constructed coherer. A surge of the shortest possible duration will cohere the coherer. The device is so arranged that the coherer remains cohered until the record is made. There is then a movement to de-cohere. If, however, the surges are continuous a second coherer in parallel with the first prevents the decoherence and no further record is made by the multi-recorder until the surges cease. It is seen from this description that the multi-recorder will record the duration of charging an aluminum arrester.

Mechanical Details

The illustration of the multi-recorder, Fig. 5, shows the mounting of the relays and the terminal board. All wires leading from the multi-recorder are carried downward through the cast-iron pedestal shown in the illustration. The magnets for operating the record type wheels are situated just in front of the terminal board and their armatures are pivoted to move vertically forward and backward. Brass links connect the upper part of the armatures to lugs on the recording type wheels which are shifted forward or backward by the movement of the armatures. The time printing type wheels are constructed very similar to an ordinary consecutive numbering stamp, and they are mounted so that they may be easily reset. The paper roll is mounted near the center of the recorder and the paper passes under the type wheels, then between two rollers which step it through the space between the hammers and the type wheels. A carbon paper roll, the same width as the record paper, is mounted just above the record paper roll and this is passed between the type and the record paper. The carbon paper is rerolled upon a spool just in front of and above the type wheels. This spool is driven by a small chain running over a sprocket wheel fastened to the paper-advancing rollers. See Fig. 6. The printing solenoid is located under the paper-advancing rollers and padded hammers linked to the core of the solenoid *C*, (Figs. 3 and 4) are made to swing upward, striking the underside of the record paper, and causing the type to make a carbon imprint upon the record paper. When the core is released it is returned by a strong spring which also rotates the advancing rollers and moves the paper as before mentioned. The stepping is accomplished by a pawl and ratchet mechanism.

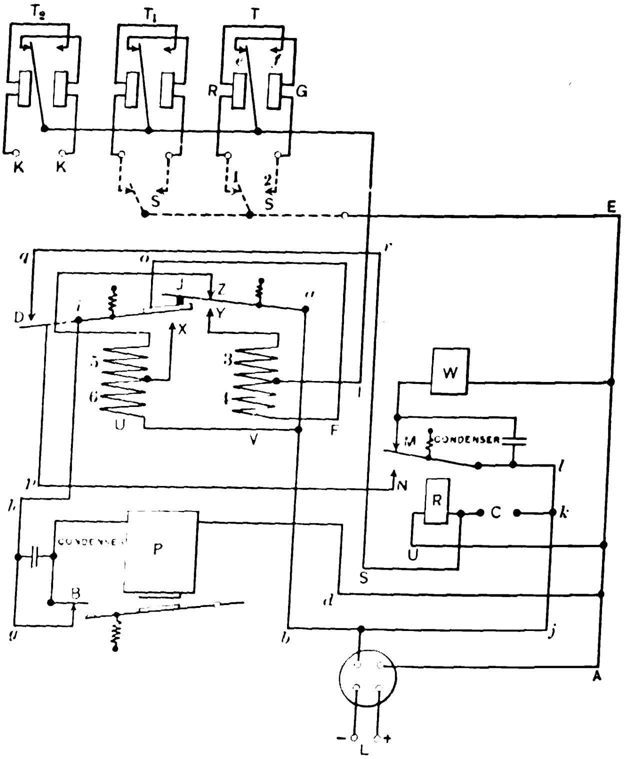


FIG. 3.

With respect to size, there is practically no difference between the two types of recorders and in fact they look very similar. Nearly all the metal frame work is made of finished brass. The machines are mounted on a slate or marble slab supported by a cast iron pedestal. The recorder is provided with a glass case having a hinged top. This renders the machine free from dust and at the same time makes it easily accessible.

Almost any part of the mechanism may be viewed through the encasing glass. The record paper feeds out under the lower front edge of the case and it is provided with a straight edge so that portions of the record may be torn off.

Wiring. ' Now that we have described the functions of the multi-recorder in general, more detailed description of the wiring between the electromagnets and interlocking contacts will be given for those who wish to follow more minutely the method of operation.

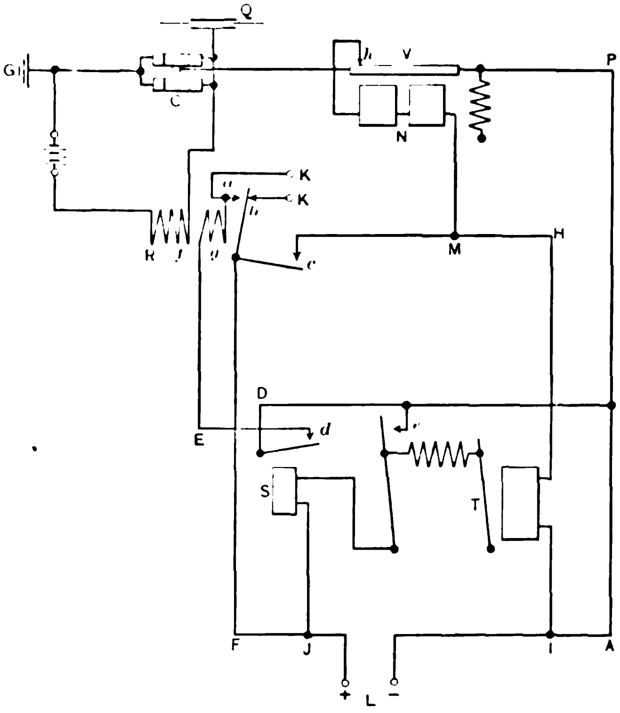


FIG. 4.

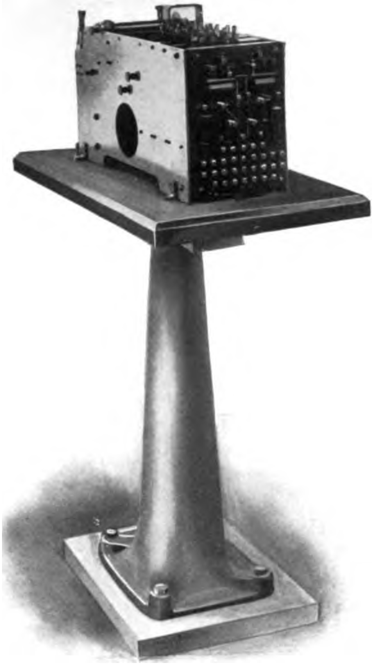
In this part of the paper it is the purpose of the writers to describe as briefly as possible the two types of multi-recorders which have been built and which operate successfully. The recorders will be referred to as multiple-connected and series-connected. Both recorders are very similar in construction with the exception that the series-connected recorder makes use of a moving element which makes a pencil line record, while the multiple-connected machine makes a type-printed record of all switching operations, etc.. The writers are indebted to Mr. A. H. Davis, of the Lightning Arrester Laboratory, for this series connection. References to Fig. 1 and Fig. 2 will show wherein the records differ. It will be noted that in each record the time is printed to the second, *i.e.*, 2A6 44—3 is to be interpreted thus, Mônday, a.m., 6th hour, 44th minute, third second. In Fig. 1 let us assume that line No. 1 is a line which is to show the operation of the switch. The paper strip used for this record has parallel colored lines in sections of five drawn the length of the paper. Each of these lines is a center line upon either side of which the recorder draws its record line. The center lines are colored so that the records may be more easily read. Whenever line No. 1 is at the left of the center line, the indication is that the corresponding switch is open. The point at which line No. 1 crosses its center line shows the time when the switch was operated. Whenever line No. 1 is at the right of its center line the indication is that the switch is closed. Records of other operations are similarly shown.

In Fig. 2 the operation of the switch is indicated by the printed number and letter, *i.e.*, 1*G* indicates that the switch is open,—1*R*—that it is closed. The time at which the switch operates is shown opposite the record print and at the left of it.

Let us now take the multiple connected recorder and go through with its principles of operation. This recorder may be designed to operate satisfactorily on any direct current circuit of from 15 to 120 volts. If the recorder is to be operated on a voltage higher than 120 it would be desirable to put resistance in the various circuits to limit the current. Fig. 3 shows the connection for the low voltage type. S (S_1 to S_{30}) represents the contacts which are operated by the switching, or similar operations that are to be recorded. R and G are the magnets which turn the type-wheels that print the record. T (T_1 T_2 to T_{30} at the top of the figure) is a special quick break contact mechanism which is tied to the armature of R and G by means of a toggle spring (not shown in the diagram.) This mechanism and its contacts, *e* and *f*, is placed at the top of the recorder and may be seen in the accompanying illustration (Fig. 5). V is a relay coil having a high resistance winding (4) and low resistance winding (3). U is a relay coil having winding similar to V, 5 being the low resistance winding and 6 the high. P is the printing and paper-stepping solenoid.

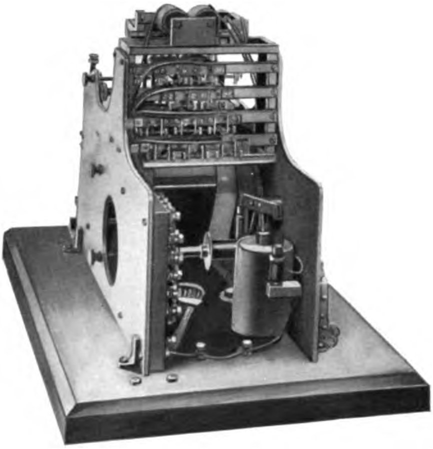
Let us now go through with an example of the operation of this recorder. Suppose we select an oil switch that has been connected to operate the contacts *S* of this recorder. These contacts, *S*, may be mechanically fastened to the switch or *S* may be a three-point relay connected in the control circuit so that the contact 2 is closed and contact 1 open when the green light is on, and contact 1 is closed, and 2 open when the red light is on. Assume that the oil switch is about to be opened, the previous closing of the oil switch had broken the contact 2 and closed the contact 1 of *S* as shown. Also it had broken contact *f* and closed contact *e* of the quick break contact *T*. The oil switch opens, breaks contact 1 and makes contact 2 at *S*. This allows the current to flow from line *L*, shown at the bottom of the figure toward the right through the connecting wire *A*, *E* to the contact 2 at *S* through magnet *G* and contact *e* of *T* down through wire, *H*, *I*, through the high resistance coil 4 of relay *V*, through wire *F*, *O* contact *J* wire *a b* back to the line *L*. The current which flows through this circuit is too small to cause the armature of *G* to move, and, therefore, the circuit through *e* at *T* remains unbroken. This current is, however, sufficiently strong to cause coil 4 of relay *V*, to draw its armature against contact *Y* and mechanically close contact, *X*. During this movement contact *J* is not broken and it remains closed until contact *Y* is open while contact *X* remains closed. As soon as contact *Y* is closed the current is free to pass through the low resistance coil 3 of relay *V* and since the current is now much larger due to the lowering of the resistance of the circuit the magnet *G* moves its armature and the type wheels linked to it (not shown in the figure). The motion of this armature also breaks the circuit at contact *e* of *T*, and closes contact *f* of *T*. This puts the contacts of *S* and *T* in relative positions at rest. It may readily be seen that the contact *J* is necessary in order that the second phenomenon may not interfere with recording the first. If, however, two or more phenomena should occur simultaneously or nearly so, records of all the phenomena will be made in one operation of the recorder. It should be noted that in breaking contacts, *J* and *Y*, the common connection *I H* for all the operating contacts, *e* and *f* of *T* ($T_1 T_2$ to T_{30}) is open-circuited at *Y* and *J*, so that should another phenomenon occur while contact *J* is open (contact *J* cannot be opened without opening contact *Y*), the entire operation of the recorder for this new phenomenon will not take place until the first record just being described has been finished. The current which operates *G* also holds contact *Y* of the relay *V* closed until the circuit is broken at contact *e* of *T*, when relay *V* is de-energized, contacts *Y* and *J* are opened, and contact *Z* is closed by a spring return. When the armature *V* is returned to make contact *Z*, contact *X* of relay *U* is held closed by the current which flows from the line *L* through wire *A c d*, printing magnet *P*, contact *B*, wire *g h i*, contact *X*, the high resistance coil 6 of *U* through wire *b*, back to the line *L*. This current is too small to operate the printing and stepping magnet *P* but is sufficiently large to cause relay *U* to hold contact *X* closed. At once the contact is made at *Z*, the current flows through the path from line *L* through wire *A c d*, printing solenoid *P*, contact *B*, wire *g h i*, contact *X*, low resistance coil 5 of *U*, upward through contact *Z*, and downward through wire *a b*, back to the line *L*, and operates the printing solenoid *P*. Closing the circuit of solenoid *P* on operating current throws a set of hammers against the type wheels, thus making the printed record. When the stroke of solenoid *P* has reached its limit the circuit is automatically opened at contact *B* and relay *U* losing its energy allows contact *X* to be opened by a spring on its armature, which also closes contact *J* as in the original position. The opening of contact *B* is purely a mechanical operation and is accomplished by the core in solenoid *P* reaching its limiting position. Solenoid *P* being also deenergized by the breaking of contact *B* releases its core and it is returned by a strong spring which stops the paper along for about a quarter of an inch. The above cycle of operation having been passed through, it will be seen that every part of the recorder is back to its original position and the recorder is now ready for the next record. Should two or more switches be operated simultaneously, a corresponding number of recording type wheels would be moved. For example —if *S* and S_1 should close their contacts 2 (or 1) at the same time, then the coils *G* (or *R*) of *T* and T_1 would be thrown in the circuit in parallel. They would move their corresponding type wheels simultaneously when their circuits were made to carry sufficient current to operate them and relay *V* would close its contact *Y*. The relation between the resistances of coils 3 and 4 of relay *V* is so proportioned that any number of records may be made simultaneously.

The time printing type wheels are operated by a solenoid whose circuit is closed and opened by a relay of the clock circuit. A seconds beating clock has attached to its pendulum a pair of



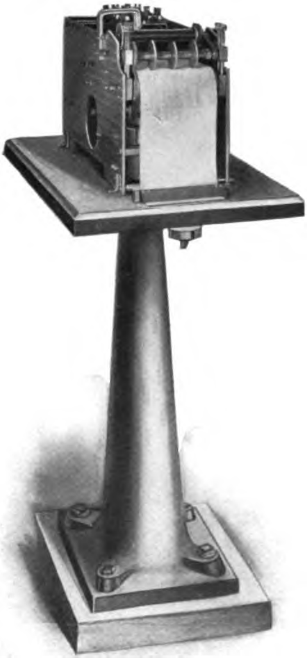
[CREIGHTON, NICHOLS AND HOSEGOOD]

FIG. 5.—BACK VIEW OF THE PRINTING MULTI-RECORDER.



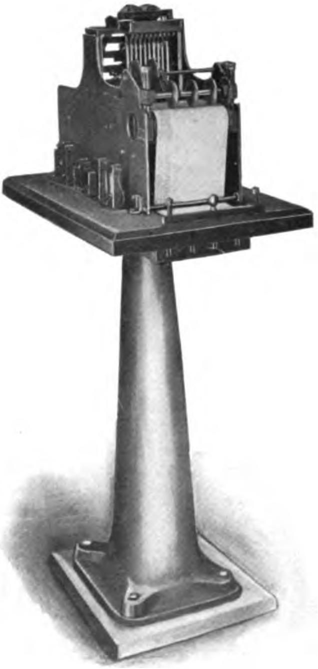
[CREIGHTON, NICHOLS AND HOSEGOOD]

FIG. 8.—BACK VIEW OF THE PENCIL TYPE OF MULTI-RECORDER.



[CREIGHTON, NICHOLS AND HOSEGOOD]

FIG. 6.—FRONT VIEW OF THE PRINTING MULTI-RECORDER.



CREIGHTON, NICHOLS AND HOSEGOOD]

FIG. 9.—FRONT VIEW OF THE PENCIL TYPE MULTI-RECORDER.

simple contacts (not shown in figure) which are connected to *C* in the diagram of Fig. 3. When the clock ticks the circuit of relay *R* is closed, opening the circuit of the type wheel solenoid, *W* at contact *M* which allows the advancing pawls of the type-wheel mechanism to be stepped backward by a spring. When the clock circuit is opened, then the relay *R* is released and the circuit of *W* is closed at contact *M* which advances the pawls on the type-wheels, moving them forward and causing the wheels to advance one second. The above cycle is repeated, every second. Should a switching operation take place at such a time that the printing would occur just as the time printing wheels were advancing, it would not be possible to read the time on account of the failure to print properly, as before mentioned.

This possible failure of the recorder is eliminated by contact *D* which is in a circuit in parallel with the clock circuit. Normally when switching occurs with contact *N* open the contact *D* has no function; but should the contact *N* be in a closed position at the time that relay *U* closes, (which closes contact *D* as well as contact *X*, contact *D* would complete the circuit of the clock relay *R* through contact *N* and prevent the spring from opening *N* when the clock contact opened.

This circuit may be traced as follows. Starting from line *L* the current passes through the wire *A t u* relay *R* wire *S r q* contact *D* downward through wire *p*, contact *N* wire *l j* back to line *L*. Normally when the recorder is not operating the circuit when the clock contact closes is as follows. Current flows from line *L* through wire *A t u* relay *R* clock contact *C* wire *k j* back to line *L*. The ticking of the clock then opens and closes contacts *M* and *N* alternately, closing *M* causing the time wheels to be moved and closing *N* making it possible for contact *D* to prevent the opening of relay *R* when the movement of time wheels is to be delayed. Relay *R* will, however, be opened when both contact *D* and the clock contact are opened, since this opens the circuit of relay *R*. It must be understood that this delaying of the movement of the type-wheels is only a fraction of a second, and does not therefore throw the time of the wheels behind that of the clock.

RECORDING OF LIGHTNING DISTURBANCES AND SURGES

Reference to Fig. 4 will show the connection of the apparatus used to operate the recorder for high frequency disturbances on the transmission line, previously referred to in this paper. *Q* is a condenser connected between the transmission line and the special coherer *C* which is connected to ground as shown. *V* is the tapper which decoheres coherer *C*. *R* is a relay which may be closed only by current in the coherer circuit. *T* is a time limit relay to close the circuit of the relay *S*. *L* is the source of direct-current power to operate the mechanism which is the same source as shown in Fig. 3. The terminal *K K* should be connected to the corresponding points lettered *K K* in Fig. 3 of the multi-recorder.

The operation of the discharge recorder is as follows: High frequency coheres coherer *C* and energizes relay coil *f* of *R* opening contact *b* and closing contacts *a* and *c*. Closing contact *a* performs the same function as one of the contacts (1) of *S* in Fig. 3 and causes the recorder to print the exact time at which the disturbance commenced, and also printing the letter *R* which will indicate that the disturbance is on the transmission line. Contact *a* also closes the circuit of the holding coil *g* of relay *R* as follows: Current flows from line *L* through wire *A B D* contact *d* (which is normally closed), wire *E*, coil *g*, contact *a* downward through wire *F* back to line *L*. When relay *R* operates, contact *c* closes a circuit as follows: Current from line *L* flows through wire *F* upward through contact *C*, wire *H* downward through the coil of time limit relay *T*, through wire *I* back to line *L*. The time limit relay *T* operates about a quarter of a second after contact *c* has closed and closes contact *e*. The circuit through contact *e* is as follows: Current flows from line *L* through wire *A B* through contact *e* relay *S* wire *J* back to line *L*. The relay *S* opens contact *d*, and therefore causes coil *g* of relay *R* to lose its energy. Contact *c* also closes the circuit of the tapper coils of *V* as follows: Current from line *L* flows through wire *F*, upward through contact *c*, wire *M N*, the coils of *V*, contact, *h* wire *P A* back to line *L*. The armature of *V* will now vibrate like the armature of an electric bell and the hammer at the left end of the armature will tap the coherer tubes *C* alternately and decohere them. The coherers *C* in turn will break the circuit of coil *f* in relay *R* as soon as the high-frequency disturbance on the transmission line has ceased.

If the disturbance is of very short duration (less than a quarter of a second) coil *f* of relay *R* will at once lose its energy as just explained, but the armature of relay *R* will not be released until the time relay *T* has operated relay *S* and broken the circuit of the holding coil *g* of relay *R* at contact *d*. This then will delay the breaking of contacts *a* and *c* and consequently the making of contact *b* which would be accomplished by the spring on the armature of relay *R*. Delaying the breaking of contact *a* and the making of contact *b* is necessary in order that the recorder (which is operated by closing contact *a* or *b* as before explained) will have time to go through its first cycle of operation which will make an *R* record before contact *b* is closed which in turn would again cause the recorder to operate but this time it would make a *G* record. Should the contact *b* be closed too soon the recorder might not complete its first record and therefore, no disturbance would be indicated on the record sheet. Now, if the disturbance is of long duration (several seconds or minutes) the coherer will be kept cohered and coil *f* of relay *R* will hold contacts *a* and *c* closed even after relay *S* opens the holding coil circuit *g* at *d*. The recorder as before stated has printed the letter *R* on the record sheet together with the time at which the disturbance commenced. When the disturbance ceases, coil *f* of relay *R* loses its energy and contact *a* and *c* open. When contact *a* is opened and *b* closed the particular record type-wheel recording the above phenomena is shifted so that it will print *G* instead of *R* and also the time at which the disturbance ceased. The time of duration of the disturbance can be easily seen by noting the difference in time of these two records.

Incidentally this last operation would prove very valuable in connection with the charging of electrolytic lightning arresters. The time at which the charging was done would be recorded and also the duration of each charge would be shown.

It will be seen from Fig. 3, and the previous reference to it, that a magnet *R* or *G* must operate and turn its type-wheel before the printing can take place and that the whole network is so devised that each operation must come in its regular order.

As before mentioned the two recorders are very similar in mechanical construction. The essential differences between the two are in the electrical principles and in this particular case in the fact that the series-connected recorder has been provided with pencils instead of type wheels. However, it is possible to design either recorder with pencils or type-wheels.

In the illustration, Fig. 9, the arrangement of the pencil operating magnets may be seen.

We will now consider the electrical connections and operation of the series-connected recorder. Fig. 7 shows the diagram of connections.

It will be noted that all the magnet coils *R* and *G* are connected in series and the operation of the pencils depends upon the short circuiting of either coil *R* or *G*. *S* shows the contacts of a six-point relay which is operated by the switching, the same as in the multiple-connected recorder. *U V* is a relay having a double winding as shown. *X Y* is a two-coil relay, each magnet of which operates upon the same armature. *Z* is an electrically operated mechanical interlock which locks the pencil bars when they are at rest. This interlock consists of an electrically operated bar having upon its lower edge a number of *V* shaped projections which normally rest against similar projections extending upward from extension of the pencil magnet armatures. The point of the *V* projection on the armatures will be on one side or the other of the projections on the interlocking bar and the pencils may not be moved except when the interlocking bar is raised.

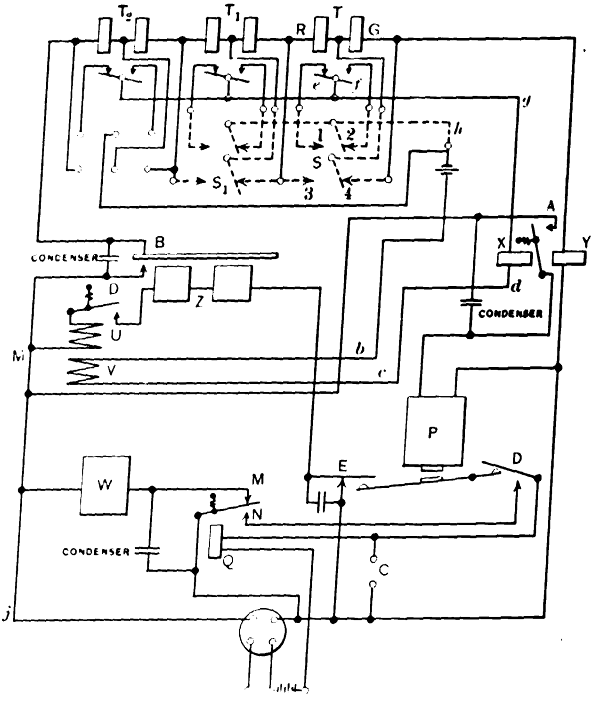


FIG. 7.

When an oil switch is closed one of the six-point relays

S operates so that contacts 2 and 4 are opened and contacts 1 and 3 are closed. Consider, first, the closing of contact 1. The circuit from the low voltage battery *C* shown in this line, is completed through contact 1 as follows: Current flows from battery *C* through wire *a b*, operating coil *V* of relay *M*, through wire *c d*, through coil *X*, wire *g*, contact *e* of *T*, through contact 1 of *S*, back to the battery *C* through wire *h*. Current in coil *X* prevents the closing of contact *A* when coil *Y* is energized. Current in coil *V* closes contact *D* which completes the circuit of relay *Z* to line *L*, as follows: Current flows from line *L* upward through contact *F* through wire *i*, the coils of relay *Z*, through contact *D* of relay *M*, downward through wire *j* back to line *L*. Relay *Z* closes contact *B* and also mechanically unlocks the pencils so that they are now free to be moved by their magnets *R* or *G*. The pencils are kept locked in place because the paper moving under the pencils might pull them out of place should they be free to move. Closing contact *B* sends current through all coils *R* or *G* in series which are not short circuited by the contacts 3 or 4 at *S*. In this case, coil *R* is short circuited by contact 3. Therefore, the current energizes magnet *G* and its armature moves pulling the pencil to the right, opening contact *e* and closing contact *f*. Breaking contact *e* opens the circuit of coils *X* and *V*. De-energizing *V* does not break contact *D* as the relay is held closed by the holding coil *U*. De-energizing *X* permits relay *Y* to close contact *A* which completes the circuit from the line *L* through the printing and stepping solenoid *P*. The printing takes place the same as in the case of the multiple connected recorder (except that the only part of the record which prints is, obviously, the time) and the circuit of coils *Z* and *V* is opened at *E*; their armatures are released, breaking contacts *D* and *E*. Opening contact *B* opens the circuit of coil *Y* which in turn releases its armature and opens contact *A*; this breaks the circuit of the printing solenoid *P*, its core is released and the paper advancing rollers are moved the same as described in the other recorder. The clock mechanism and connections are substantially the same in both recorders, and the diagram of connections may be seen in Fig. 3 or Fig. 7.

The discharge recorder terminals *K K* of Fig. 4 should be connected to the operating coil of one of the six-point relays, *S* (S_1 S_2, to S_{30}).

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(*Subject to final revision for the Transactions.*)

PROPAGATION OF IMPULSES OVER A TRANSMISSION LINE

BY J. H. CUNNINGHAM AND C. M. DAVIS

The investigations outlined here were made last summer on the artificial transmission line described in a previous paper.[1] Briefly, this line consists of 400 glass cylinders 6 in. (15 cm.) in diameter and 4½ ft. (136 cm.) long. Upon these are wound 240 turns of No. 8 B. & S. copper wire and the inner surface is lined with tinfoil, cut so as to avoid secondary currents. The constants of the total line are as follows:

Capacity	1.153×10^{6} farad.
Inductance	0.411 henry
Resistance	96 2 ohms

Natural period $= \dfrac{1}{4\sqrt{L\,C}}$ 363 cycles (quarter wave)

Equivalent length $= \dfrac{186{,}000}{4\,f}$ 128 miles = 206 km.

The line is equivalent to one wire 128 miles long with resistanceless ground return, that is, one phase of a grounded Y system.

Voltage impulses were sent over this line and were produced by suddenly impressing a continuous voltage upon the low tension winding of the step-up transformer to which the line was connected. This caused the current, and with it the flux, to rise, and in turn induced a voltage in the high-tension winding and the line.

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[1] *Design, Construction and Tests of an Artificial Transmission Line,* PROCEEDINGS A. I. E. E., January, 1911, p. 87.

Difficulty was experienced in finding a suitable switch with which to close the circuit. After trying an ordinary knife blade switch, a solenoid operated carbon contact switch and an oil switch, a very simple drop switch proved to give the best results. This consisted of a copper rod dropping about seven inches into a cup of mercury. The contact was always positive and gave currents and voltages free from all irregularities due to arcs or multiple contacts.

The transformer used was rated at 125 cycles, 3 kw. 110/2200 volts, and was modified in construction by removing one end of the core in order to increase the magnetic energy, $\frac{Li^2}{2}$, so as to get an impulse of sufficient energy to be observed by the oscillograph. This open magnetic circuit also eliminated the effects of saturation.

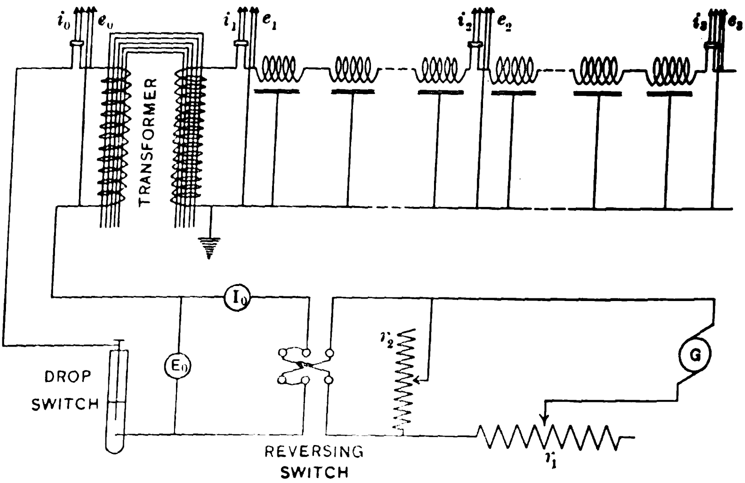

FIG. 1.

The method of operation can be described by reference to Fig. 1. The transformer was connected to the generator with the resistance r_1 in series and the resistance r_2 in parallel. The reversing switch, drop switch and oscillograph vibrators were connected as shown. The object of the arrangement of resistances r_1 and r_2 was to control the magnitude and character of the impulse by controlling the current and voltage.[2] With the

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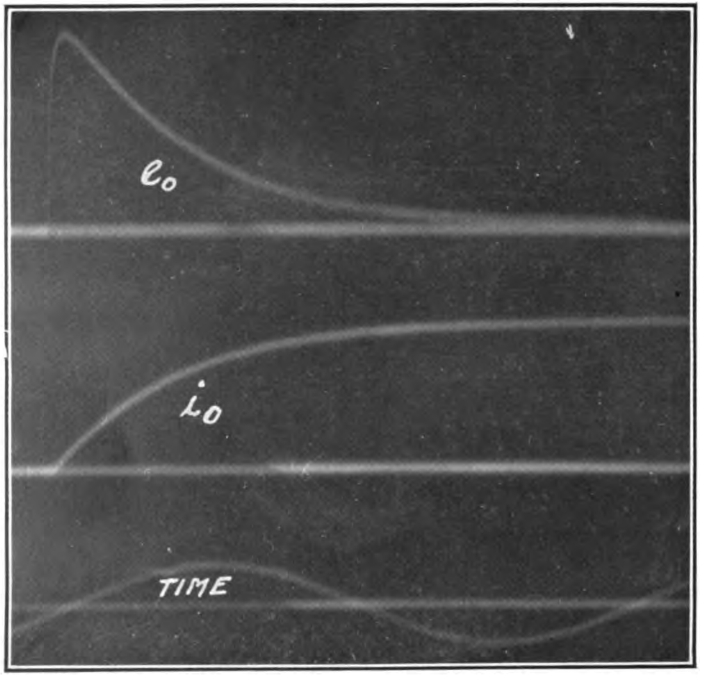
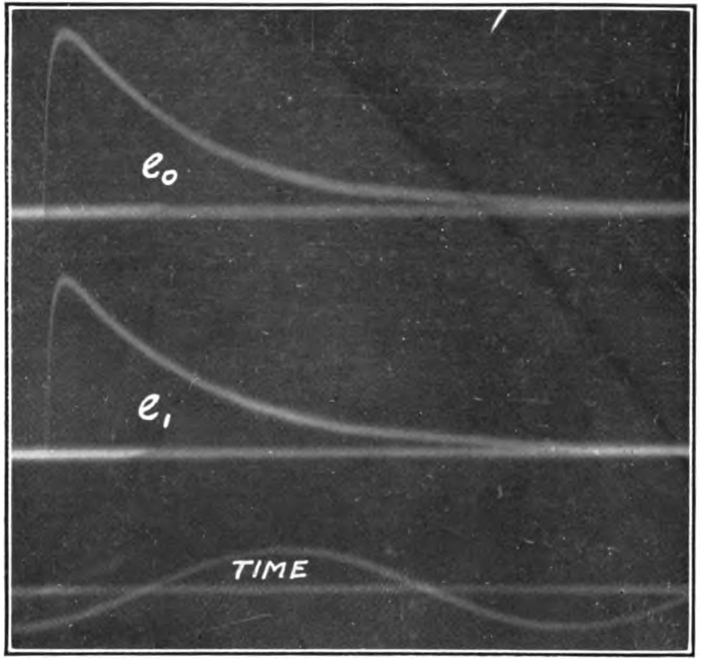
[2] See *Disruptive Strength with Transient Voltages* by J. L. R. Hayden and C. P. Steinmetz, TRANSACTIONS A. I. E. E., 1910, Vol. XXIX, Part II, page 1125.



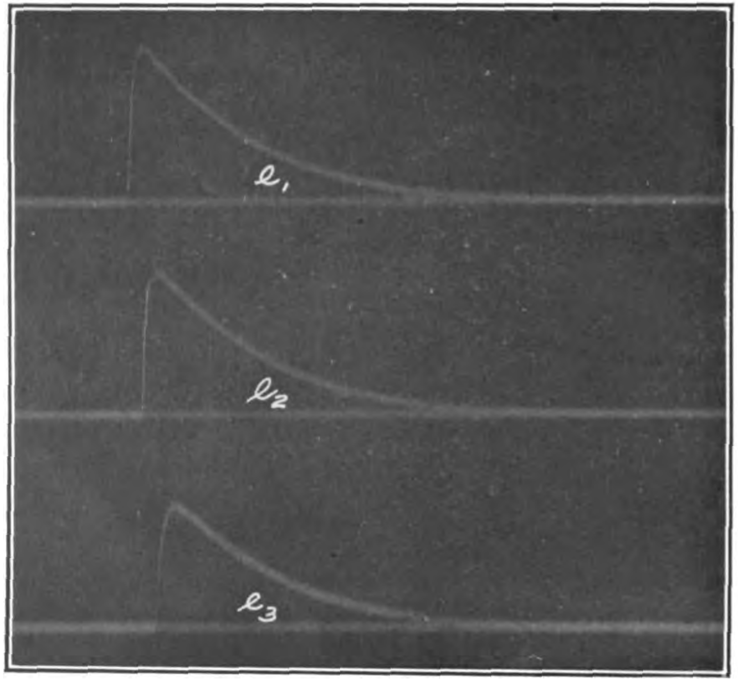
[CUNNINGHAM AND DAVIS]

FIG. 2.—LOW-TENSION VOLTAGE AND CURRENT.
No Line On.



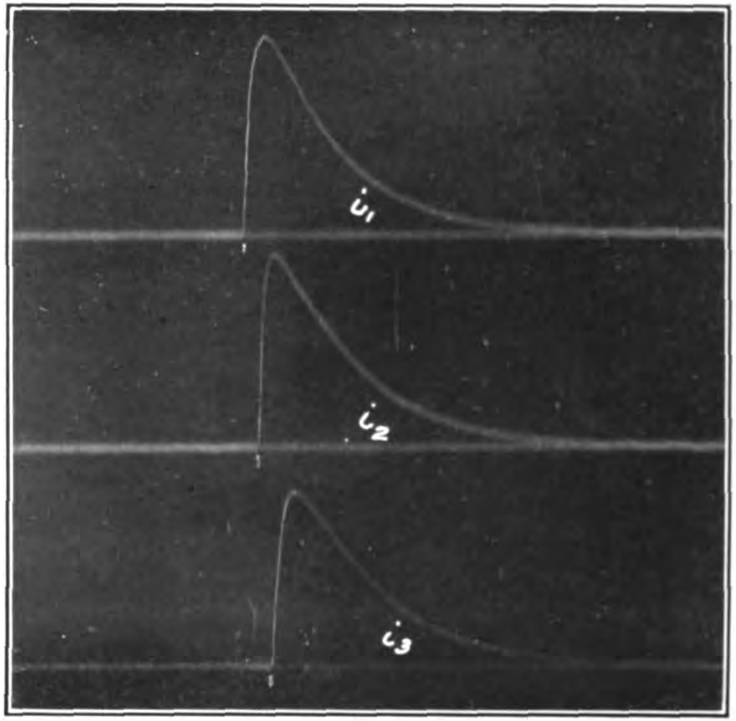
[CUNNINGHAM AND DAVIS]

FIG. 3.—LOW-TENSION VOLTAGE AND HIGH-TENSION VOLTAGE.
No Line On.



[CUNNINGHAM AND DAVIS]

FIG. 4.—VOLTAGES AT THE BEGINNING, MIDDLE AND END OF LINE.
Line Closed Through 600 Ohms.



[CUNNINGHAM AND DAVIS]

FIG. 5 —CURRENTS CORRESPONDING TO FIG 4.

drop switch closed the resistance r_1 was adjusted to give the desired current, I_0, and with it open the resistance r_2 was adjusted to give the desired voltage E_0. Tests were made with $I_0 = 25$ amperes and $E_0 = 75$ volts, and with $I_0 = 25$ amperes and $E_0 = 225$ volts.

The reversing switch was inserted so that by throwing it over and back each time before taking a record the residual magnetism was constant in direction and amount.

With I_0 and E_0 adjusted the drop switch was closed and oscillographic records of the voltage and current were made on the low tension side of the transformer, at the beginning, at the middle and at the end of the line. Time was marked by a 60-cycle voltage wave. Records were made thus with the transmission line open at the end, short circuited at the end and closed by 600 ohms $\left(=\sqrt{\frac{L}{C}}\right)$ non-inductive resistance.

Several of the oscillograms taken are reproduced herewith, and a study of them is interesting. Fig. 2 shows the current and voltage on the low tension side of the transformer when the line is not connected to it. Fig. 3 shows the same impulse on both the low-tension and high-tension sides of the transformer: e_0 and e_1 respectively. The curve e_1, then, gives the general shape of the voltage impulse impressed upon the line. A 60-cycle timing wave is also shown from which it is observed that the impulse lasts about one cycle, or 0.017 second.

If the line were infinite in length the impulse would travel out over it until all its energy was dissipated and it would thus vanish. This condition can be reproduced on a line of finite length by closing the end with just enough non-inductive resistance to absorb all the energy of the impulse. This resistance is numerically equal to $\sqrt{\frac{L}{C}}$. Figs. 4 and 5 show the voltage and current of an impulse propagated over such a line. The curves e_1 of Fig. 4 and i_1 of Fig. 5 show the voltage and current at the beginning of the line, e_2 and i_2 at the middle, and e_3 and i_3 at the end of the line.

The figures just referred to show very nicely how the impulse progresses along the line, dying out in intensity as it goes. The velocity of propagation can also be observed by noting the point at which the successive curves begin. Thus e_2 begins a little later than e_1, similarly e_3 begins a certain time after e_2 and twice this time after e_1. The same may be observed in the case of i_1, i_2 and i_3. The velocity of propagation was measured as 0.78 milli-second; that is, 0.78 milli-second after the drop switch was closed the impulse reached the end of the line. Since the velocity of propagation over a straight transmission line in air is known to be that of light, 3×10^{10} cm. per sec. (neglecting resistance), the artificial line has an equivalent length of 233 km. (145 miles), or about 13 per cent longer than calculated from the measured inductance and capacity.

If the line is not infinite in length, and furthermore if it is short enough so that the impulse does not die out before reaching the end, it is interesting to see what takes place. The impulses which are impressed upon the line are impulses of *energy*, although the oscillograms we obtained of them show only the component parts, the voltage and the current. On a line of infinite length the impulse of energy would travel along until it was all dissipated, but on a short line it reaches the end and depending upon the electrical condition at the end it is disposed of in various ways. We will consider two cases in detail; first when the line is open, and second, when it is short circuited.

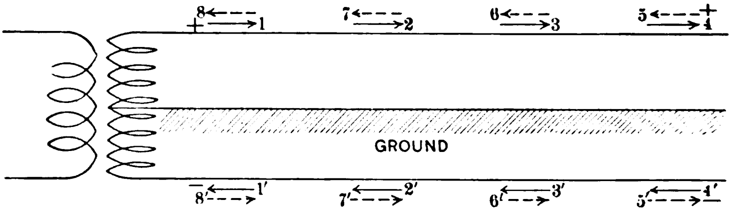


FIG. 6.

Taking the case of the open line and referring to the diagram, Fig. 6, the transmission line is represented connected to a transformer the middle of which is grounded.

Assume that the impulse is of such polarity that when it is impressed upon the line it makes the upper line positive as indicated. The voltage of the impressed impulse causes corresponding currents to flow as shown by the arrows 1 and 1′ which flow in the direction corresponding to the direction of the voltage. These two currents with their voltages now travel along the line and at some later instant are at positions 2 and 2′. (The numerals are placed at the end of the arrows in the direction of propagation along the line.) At a later instant they are at 3 and 3′, and finally reach the end of the line, 4 and 4′. Now the energy is at the end of the line but it will not stay there if there is a possible outlet for it. Obviously, since the line is open the only outlet is back the way it has just come; thus, the current reverses and the energy travels back to the home end of the line as indicated by the dotted arrows. Since at the moment of the reversal the far end of the line becomes the source of energy and the current takes the direction as shown by the dotted arrows, the voltage must have a direction as indicated by the plus and minus signs at the far end.

The case of the short circuited line is represented by the diagram Fig. 7, where, as before, the impulse is represented as starting with the currents 1 and 1′, and the voltage as indicated. Similarly this impulse travels along the line until it reaches the far end, but now there is an outlet for the energy afforded by the short circuit so the currents in the two wires merely keep on flowing around the circuit and the energy flows back as indicated by the numerals. In this case, at the moment of reversal, when the far end becomes the source of energy, the direction of the voltage would have to be as indicated by the plus and minus signs.

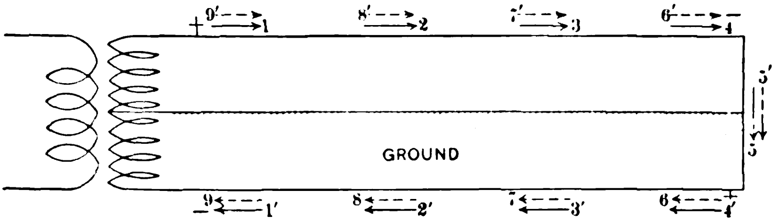


Fig. 7.

As far as the energy is concerned the two cases just described are identical; in both, the energy travels from the home end to the far end of the line and back to the home end again, and if it is not all dissipated by the time it gets back to the starting point, it will again travel out over the line, continuing thus back and forth until it dies out. We may therefore consider the energy impulse as being " reflected " each time it reaches the ends of the line. Likewise, by analogy, we may speak of the current and voltage of the energy impulse as being " reflected, " and since in this investigation we know of the energy only through the agency of oscillograms of current and voltage, it is a very useful term.

By the above study of reflection from open and short circuited lines we see, in the case of the open line, the voltage remains in the same direction and the current reverses after reflection, while in the short circuited line the opposite is true; the current remains in the same direction and the voltage reverses.

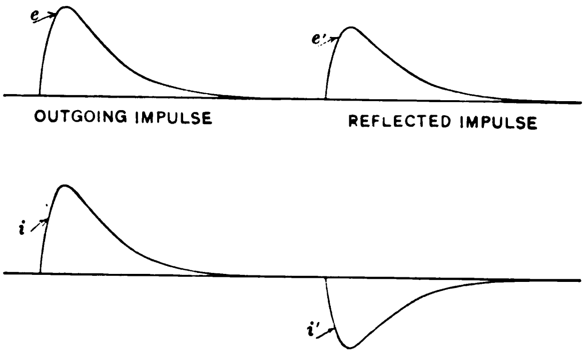


FIG. 8.

There are other conditions which may exist at the far end of the line, viz., closed by inductance, by resistance, or by any combination of each. When the line is closed by an inductance part of the current passes over it, as with a short circuit, and part returns by the same wire it started over. Thus the reflection is intermediate in nature between the reflection from open circuit and that from short circuit.

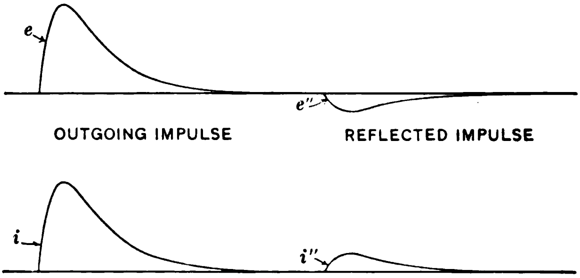


FIG. 9.

Figs. 6 and 7 show the line as composed of two line wires with the ground midway between them electrically. On the artificial line the connections were such as to give only one wire with a ground return. This would be the case in a three-phase Y-connected system with grounded neutral and two of the line wires disconnected.

In order to get a clear idea of the way these impulses and their various reflections may be recorded by an oscillograph, let the line be assumed so long that the out-going impulse has time to die away before the reflected impulse returns to the home end of the line. If an oscillogram of the voltage and current were taken at this end it might look something like Fig. 8, which shows the outgoing impulse, *e*, *i*, and the same impulse reflected from the open end of the line *e'*, *i'*. Similarly another oscillogram may be assumed giving the reflection from an inductance. This is shown in Fig. 9. Here the inductance is taken of such a value that it acts nearly as a short circuit, that is, the voltage reverses.

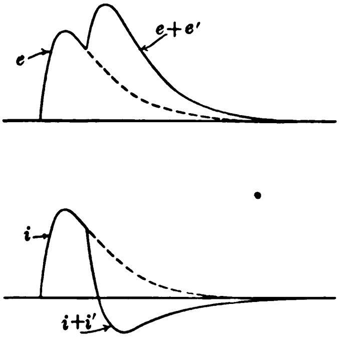


FIG. 10.

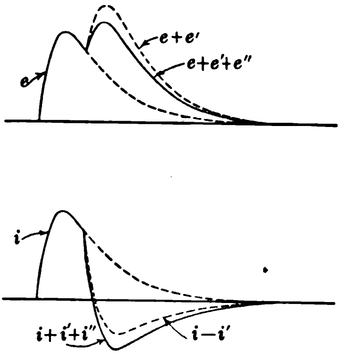


FIG. 11.

Should the line be short in comparison with the length of the impulse the reflected wave will return before the outgoing impulse has died out, and an oscillogram would appear as shown in Fig. 10, where the reflected impulse is combined with the original impulse. Further, when the oscillogram is taken at the beginning of the line it will show not only the reflection from the far end but simultaneously with it the second reflection from the transformer coil at the beginning of the line. The latter is of the nature of that shown in Fig. 9. Finally, then, an oscillogram taken at the beginning of the line would appear as in Fig. 11. An actual oscillogram is shown in Fig. 12 which gives e_1, i_1 and a 60-cycle timing wave when the line is open at the far end.

When the line is short-circuited at the end, corresponding reflections exist, but with the voltage instead of the current reversed after the first reflection. Fig. 13 is an oscillogram taken at the beginning of the line; Fig. 14 shows the progression of the current along the line.

In the oscillograms just referred to it will be noticed that there is more than one reflection, in many cases three are easily seen. This means that the impulse does not die out until it has traversed the length of the line more than six times. The reflections after the first one may be analyzed in the same manner as outlined above.

It is interesting to investigate the agreement between the observed impulses and those calculated from the line and circuit constants. Obviously, from the observed impulses the line constants may be calculated, and by comparing these with the line constants determined by observation with 60-cycle steady voltage, the change of the line constants due to the transient nature of the impulse studied.

For this purpose, the oscillograms are first reduced to empirical equations by the usual method,[3] and the theoretical meaning of these equations is then studied. At present this work is not yet sufficiently completed for presentation, and will be given at some other time.

It was found that the oscillograms are best represented by exponential expressions.

For instance, with 75 volts impressed upon the transformer primary, and a transformer ratio of 10 to 1, the expressions of voltage and current were found to be:

1. No line on and transformer open circuited at the secondary

Primary impressed voltage $e_0 = 63\ (\epsilon^{-270t} - \epsilon^{-6500t})$

Primary current $i_0 = 25\ (1 - \epsilon^{-290t})$

Secondary terminal voltage $e_1 = 670\ (\epsilon^{-280t} - \epsilon^{-12800t})$

2. Line connected to the secondary terminals of the transformer, and closed through a non-inductive resistance of about 600 ohms (equal to the surge impedance):

a. At the transformer end of the line

Voltage $e_1 = 440\ (\epsilon^{-200t} - \epsilon^{-5800t})$

Current $i_1 = 0.85\ (\epsilon^{-200t} - \epsilon^{-5800t})$

b. In the middle of the line

Voltage $e_2 = 430\ (\epsilon^{-210t} - \epsilon^{-3300t})$

Current $i_2 = 0.84\ (\epsilon^{-210t} - \epsilon^{-3300t})$

c. At the receiving end of the line

Voltage $e_3 = 400\ (\epsilon^{-198t} - \epsilon^{-3600t})$

Current $i_3 = 0.68\ (\epsilon^{-198t} - \epsilon^{-3600t})$

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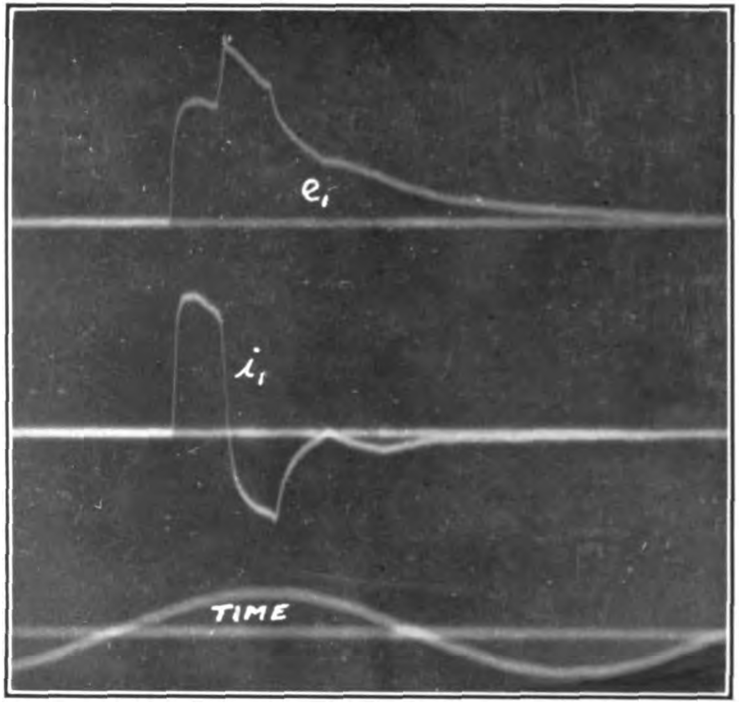
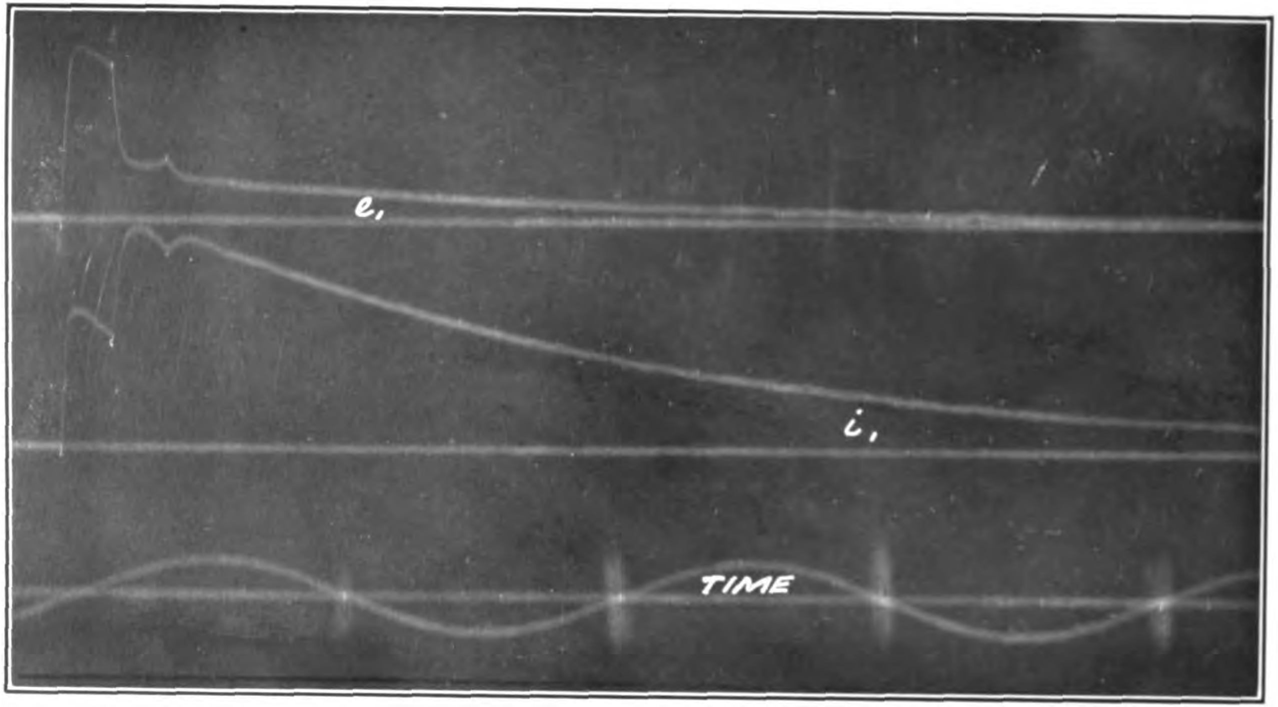
[3] See Steinmetz, *Engineering Mathematics*, Chapter VI, section C.



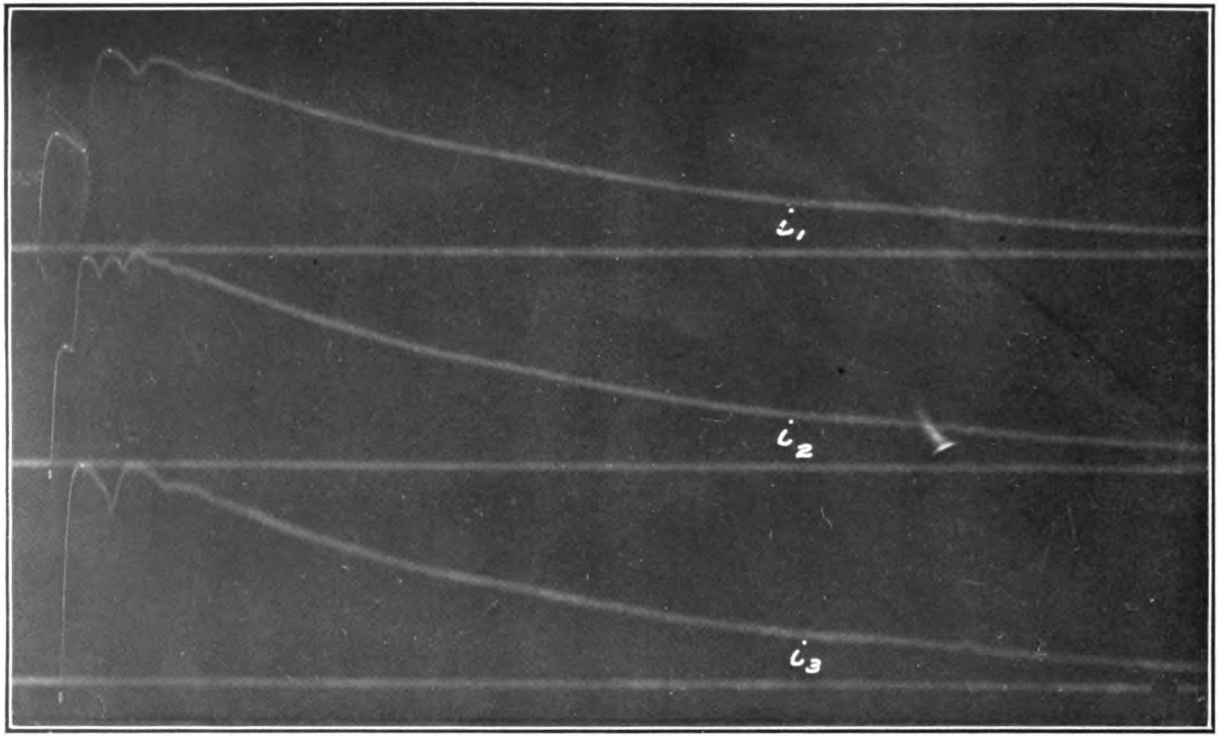
[CUNNINGHAM AND DAVIS]

FIG. 12.—VOLTAGE AND CURRENT AT GENERATOR END OF LINE
Showing Reflection from Open Receiver End.



[CUNNINGHAM AND DAVIS]

FIG. 13.—VOLTAGE AND CURRENT AT GENERATOR END OF LINE
Showing Reflection from Short-Circuited Receiver End.



[CUNNINGHAM AND DAVIS]

FIG. 14.—CURRENTS AT THE BEGINNING, MIDDLE AND END OF LINE
Line Short-Circuited.

From these equations it follows that the total energy which traverses the line as a traveling wave is:

a. At the generator end

$$w_1 = 0.83 \text{ joules}$$

b. At the middle

$$w_2 = 0.72 \text{ joules}$$

c. At the receiving end

$$w_2 = 0.61 \text{ joules}$$

Some interesting conclusions may be drawn from the data and oscillograms shown.

1. The condition under which a condenser charge or discharge is oscillatory is

$$r^2 < \frac{4L}{C}$$

which is fulfilled by this line circuit, yet the transients are not oscillatory, but are steady exponential impulses. This shows that the above equation which divides the oscillatory from the gradual transients in a circuit containing massed resistance, inductance and capacity, does not apply to the line circuit with distributed resistance inductance and capacity. This means that in a circuit with distributed constants, oscillatory and non-oscillatory transients can occur, and the nature of the transient, whether oscillatory or not, depends on the origin of the transient. This is in agreement with previous theoretical investigations.[4] Thus non-oscillatory single impulses may occur in transmission lines, cables, transformer windings, etc.

2. In Figs. 4 and 5 the current and voltage impulses coincide, and the magnetic and the dielectric component of the electric field reach their maxima simultaneously. That is, there is no surge of energy, but a steady propagation of energy along the circuit, or a traveling wave.

In the impulses considered in this paper we thus have the simplest and at the same time a typical case of a traveling wave; that is, a transient propagation of energy without oscillation, but with the current in phase with the voltage.

The other extreme is the stationary oscillation without propagation, or a typical standing wave, as it has frequently been recorded. In it the energy surges between the magnetic and the dielectric field, without any propagation of energy along the circuit, and current and voltage are in quadrature with each other.

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[4] Steinmetz, *Transient Phenomena and Oscillations*, p. 441.

In the reflected impulse, like Fig. 12, propagation of energy as well as oscillation of energy occurs, and this oscillogram represents a combination of, or transition from the traveling wave to the stationary oscillation.

3. The second term of the exponential function represents the steepness of the wave front, and it is interesting to note that it seems to be greatest at the transition point between transformer and line, and apparently practically constant in the line at some distance from the transition point.

The most important conclusion which is evidenced by the results, as far as worked up, is that in the study of transient phenomena, circuits with distributed constants, cannot be represented even approximately by equivalent circuits with massed constants, as it is customary and permissible to do in the study of permanent phenomena, but that in circuits with distributed capacity and inductance, transient phenomena occur which have no analogy in the transient phenomena of circuits with massed capacity and inductance.

A paper to be presented at the Schenectady Meeting of the American Institute of Electrical Engineers, Schenectady, N. Y., May 17, 1912.

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(Subject to final revision for the Transactions.)

STUDIES OF PROTECTION AND PROTECTIVE APPARATUS FOR ELECTRIC RAILWAYS

BY E. E. F. CREIGHTON, F. R. SHAVOR AND R. P. CLARK

The object of this paper is several fold, first, to describe the effects of high frequencies on car wiring; second, to describe experiences with the application of the aluminum arresters to an electrical railway where lightning is especially severe; third, to describe additional devices applied to the d-c. aluminum arrester which gives it greatly diminished deterioration with only a slight decrease in protective value; and, fourth, to describe experiments on the extinguishment of d-c. arcs and the changes that have resulted in the redesign of the old magnetic blow-out arrester.

General. Some of the main points of past standard practice in the protection of railway apparatus and lines might, to advantage be briefly summarized as a beginning. Cars using direct current are protected by one or two arresters of the series gap type, and a choke coil. To diminish the strains on the car arresters and apparatus, arresters are placed along the line in greater or less numbers according to the type of arresters and the severity of lightning storms in the locality. These arresters are all of the series gap type. In fact, with the exception of the d-c. aluminum arrester, there is none that could be dignified by the name of "arrester," that has not a gap in series.

All of these standard arresters contain more or less internal series resistance. Since, in a d-c. circuit, dynamic current must always follow the lightning spark across the gap of the arrester, another distinguishing feature is the method employed in extinguishing the arc in the arrester.

In the older type the dynamic current energizes an electromagnet which produces a magnetic field perpendicular to the arc and thus drives it up a porcelain arc-chute. The elongation of the arc increases its resistance which reduces the current gradually until the arc is extinguished. This takes place when the energy of the arc is reduced to a value such that the rate of cooling makes it unstable. All this takes a measurable amount of time. In order that no serious damage shall be done to the electrodes of the gap during this time, some series resistance is necessary to limit the value of current. The series resistance is required also to furnish potential for the electromagnet. Since this resistance is in the path of the lightning the best design of arrester is the one which reduces the resistance to the minimum value without jeopardizing the life of the arrester by the destructive action of the dynamic current.

A second type of gap arrester prevents the continuance of the dynamic arc by an automatically variable series resistance which has a very high value to direct currents at 600 volts. It has a lesser resistance and impedance at higher potentials and high frequencies.

As protectors, the efficiencies of both of these arresters are limited not only by the active values of resistance but also by the presence of the series gap. The detrimental effect of the gap is reduced to a minimum by the well known application of the lightning choke coil.

The efficiency of the "gap-resistance" type varies according to the design, and they have usually proven sufficiently satisfactory in all but extremely severe lightning districts to warrant their standardization.

A third type of arrester gap uses an electromagnet in parallel with a resistance but the arc is interrupted by the mechanical movement of a plunger. This type has its application confined mostly to overhead trolley lines.

It seems unnecessary to review the varied conditions of demand for protection according to the geographical location, also the variations in demand along any particular line which is more or less overshadowed by trees and houses, as these matters are common knowledge.

THE RELATION OF CAR WIRING TO PROTECTION

As far as the writers know, very little attention has been paid to the matter of car wiring from the standpoint of protection. In many cases the wiring is such as to jeopardize the insulation of the motors and other electrical car apparatus in spite of the application of the best lightning arresters. This objectionable condition consists in placing the trolley bus wire and the ground wire in the same cable with the controller wires of the motor. When a lightning charge comes down the trolley, a portion of it passes by induction from the trolley cable directly into the car controller cables of the motor and thence into the motor. An instant later the charge passes around the wiring to the motor, but the first stroke on the insulation of the motor comes from the bus wire in the cable. Where the charge is forced to follow the wiring it is possible to retard it for an instant by means of a choke coil, and thereby give the lightning arrester an opportunity to carry it off directly to ground. But when the charge is permitted to pass directly into the motor winding by induction the protective value of the arrester is not brought into play. Even the aluminum arrester with unusually short connections is placed at a great disadvantage, and the gap type arresters with their spark potentials of 2,000 volts to 3,000 volts and their dielectric-spark-lags are utilized at a minimum of their effectiveness. Before going into this subject further, some isolated experiments illustrating the effect of induction will be given.

EXPERIMENTS IN HIGH FREQUENCY INDUCTION BETWEEN PARALLEL WIRES TO INDICATE THE RELATION OF CAR WIRING TO PROTECTION

The possibility of a lightning stroke being induced between wires on a car and thus by-passing the protection given by a lightning arrester, prompted an experimental investigation of this subject. The available space on a car is so limited that wires are generally grouped in a cable, and this condition is the most favorable to the inducing of potentials at frequencies approximating lightning frequencies. The first tests were made to determine the values of induced potentials.

Referring to Fig. 1, a large static machine with condensers consisting of four ordinary one-gallon leyden jars attached to each side of the machine, was used as a source of potential for a number of these tests. The frequency of discharge was approximately 1,000,000 to 2,000,000 cycles per second depending upon the size of the circuit and conductors used.

For the first test, two rubber covered stranded No. 6 B. & S. cables each 6 ft. long were laid parallel on a table. The cable *O P* was connected across the leyden jar terminals as shown in Fig. 1 and cable $x\,y$ had a needle gap connected across its terminals. The area $x\ y\ a$ was maintained fairly constant for all positions of test. The length of leads to needle gap was 8 ft. (2.4 m.) The distance D between conductors was varied and the values of Q at which a discharge just fails to pass at the gap Q was observed and recorded. The machine terminal gap spacing (G-gap) was maintained constant at 5 in. (12.7 cm.)as this setting gave the largest value of Q gap for any constant value of distance D.

The values of induced potentials were first measured at Q for the wires unprotected by iron pipes. Subsequently the tests were repeated with either wire enclosed in a 1 in. (2.5 cm.) iron conduit pipe and finally with both wires in a separate iron conduit pipe.

The values obtained as noted in the following tables prove that an iron pipe around a conductor does not appreciably shield it from the effects of induction under certain conditions. In fact the induced potentials are so nearly the same for the four different conditions tested that it seemed reasonable to suspect that the area enclosed by the secondary circuit is an important factor. To check this point the following test was made.

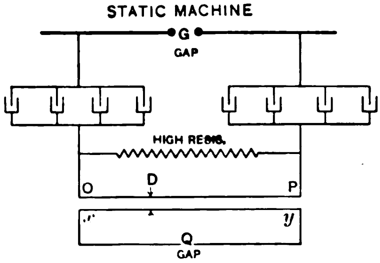


FIG. 1.

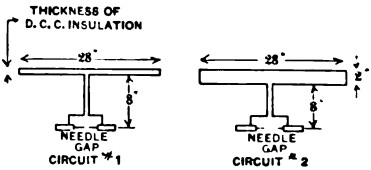


FIG. 2.

Two secondary circuits were made up, each of the No. 12 B. & S. solid cotton covered wire. The first one was made to include the smallest possible area.

This enclosed area was less than $\frac{1}{2}$ sq. in. (6.2 sq. cm.) not including the area near the needle gap which was about 8 in. (20.3 cm.) from the primary circuit. The potential induced in this secondary circuit was not measurable on a fine needle gap.

The other secondary circuit was made to include about 56 sq.

in. (361 sq. cm.) The dimensions are shown in Fig. 2. When this circuit was tested in the same position as the first the induced potential just failed to jump a needle gap setting of 0.035 in. (0.889 mm.)

Electromagnetic Induction Between Parallel Lines, 6 ft. (1.8 m.) long, "G" Gap = 5 in. (12.7 cm.)

No iron pipe used		Iron pipe on Cable *x y*	
Average *D* in.	*Q* in.	Average *D* in.	*Q* in.
.4	0.35	together	0.33
1	0.31	2	0.24
2	0.26	4	0.19
3	0.22	6	0.15
4	0.20	9	0.12
5	0.18	16	0.09
6	0.16	22	0.06
7	0.15	30	0.025
9	0.12		
12	0.11		
16	0.10		
22	0.09		
30	0.05		

Iron pipe on Cable *OP*		Iron pipe on both cables	
Average *D* in.	*Q* in.	Average *D* in.	*Q* in.
together	0.31	together	0.27
2	0.25	2	0.25
4	0.17	4	0.19
6	0.15	6	0.14
9	0.13	9	0.12
16	0.10	16	0.08
22	0.03	22	0.03
30	0.025	30	0.015

Comments on Electromagnetic Induction in Car Wiring. In order to have electromagnetic induction between two parallel circuits a current in one circuit, at least, is necessary. If lightning is to cause, by electromagnetic induction, a dangerous potential in the apparatus on cars, it is necessary to find a circuit suitable for the passage of high-frequency current. Very high frequency current cannot pass around the turns of armatures, field coils, or electromagnets, since the inductance of these devices would destroy the high frequency.

If we are to find electromagnetic induction between parallel wires of the car wiring we must look for the completion of the circuit from trolley to rail in some other path than the path taken by the direct current that operates the motors. Assume that a wire is carried from the trolley to a point underneath the car at one end, designated for convenience as the No. 1 end, and then parallels the controlling wires of the motors to the No. 2 end. In order that electromagnetic induction shall take place, the lightning current must flow out the No. 2 end of this bus. If an aluminum arrester is improperly placed between the No. 2 end of this bus and ground, the lightning has a free path through the bus to ground and motors will receive a severe induced electromagnetic strain derived from the wires parallel to this bus. In fact, under this objectionable condition, the better the lightning arrester the higher the induced potential applied to the insulation of the motors. A poor lightning arrester containing considerable resistance in series will limit the strain from the electromagnetic induction although in doing it, it will throw strains directly on the end turns of the motor connections. The cure for this trouble evidently is to avoid any connection which permits the lightning current to closely parallel the controller cables.

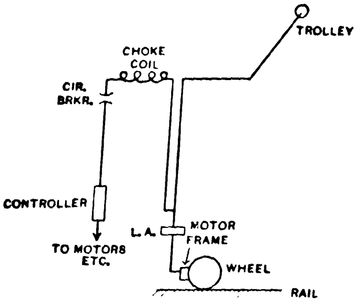


FIG. 3.

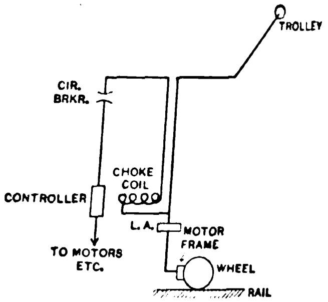


FIG. 4.

Eliminating, then, the lightning arrester from this objectionable location, what other possible path is there for lightning from the No. 2 end of the bus to ground? The only answer seems to be, electrostatic capacity to ground of the circuits beyond the No. 2 end. Some idea of the possible danger from this source may be gleaned from the experiments on electrostatic induction which will be given farther on. In closing this paragraph it is desired to caution engineers who lay out car-wiring, and repairmen who change it, to avoid placing wires in such positions that electromagnetic induction from lightning can take place.

The precaution may be put in the form of a brief rule: Avoid placing any wire that carries lightning current near and parallel, for any considerable length, to any of the wiring where damage can be done by an induced charge. Aside from the illustration of the bus wire already given, this rule may mean, specifically, to avoid carrying a lightning arrester connection, which very properly extends from the roof of a car to an arrester situated near the floor of the car, directly back on itself to the top of the car to a circuit breaker or other connection to the apparatus. The wiring shown in Fig. 3 is not so objectionable as that shown in Fig. 4 where the lightning choke coil is shunted out of full effectiveness by induction between the parallel wires leading into and away from it. The most desirable connection of the lightning arrester and choke coil is shown in Fig. 5 where the parallel rising wire is carried several feet away from the connection to the arrester. The connection shown in Fig. 6 is not quite so effective as the one shown previously in Fig. 5, due to the greater length of wire in the arrester circuit. If it seems necessary to use the connection of Fig. 6, the arrester may be placed on the roof of the car, in the vestibule, or under the car, without affecting the inductance of the circuit of the arrester. When such a connection is used, however, a larger choke coil than in Fig. 5 is necessary to offset the greater inductance of the circuit of the arrester.

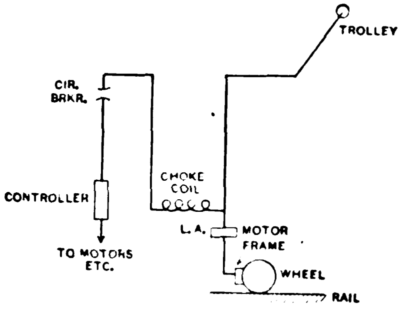


FIG. 5.

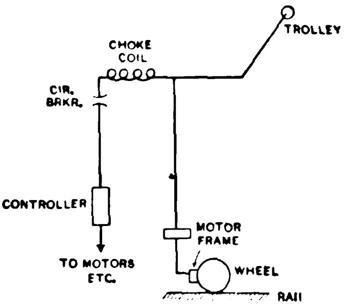


FIG. 6.

Electrostatic Induction in Car Wiring. In order to make the inquiry complete the subject of electrostatic induction should be considered. As a simple case assume that in Fig. 4 there is a lightning arrester of high internal resistance, or assume that there is no lightning arrester in a circuit of this form. When a high frequency wave comes down the vertical wire it is impeded by the choke coil and a high potential is produced between the parallel wires. An electrostatic charge in the form of a condenser charge or displacement current passes from one of these parallel wires to the other, thus shunting the choke coil. The quantity of electricity in this charge depends directly on the electrostatic capacity between the wires and the potential difference between the wires. Can this small charge do any harm? It can under certain conditions. Much depends on the electrostatic capacity of the circuit beyond the parallel wires. If, for example, the capacity of the wiring is ten times the capacity of the parallel wires, then the potential of this wiring due to a lightning stroke will be only a tenth as great as the potential across the condenser formed by the parallel wires. If the wiring beyond the parallel wires, as is more likely, has a capacity more nearly approaching the value of the parallel wires, the danger is correspondingly greater.

If the potential between the parallel wires reaches a value sufficient to puncture the insulation then, of course, the whole lightning charge goes directly into the apparatus of the car without intervention from the choke coil. Furthermore such a shunting of the choke coil will cause no burning at the point of discharge, as the dynamic current will not follow the lightning puncture between the parallel wires, and there will be nothing to indicate to an inspector that the protection of the car has been materially weakened. A very simple rule to follow to avoid such a condition is: never bring wires connected to the opposite terminals of a lightning choke coil within say, a foot (30 cm.) of each other. Electrostatic induction in car wiring is so easy to avoid that it is only necessary to call attention to the necessity of observing the possibilities of the occurrence of the phenomenon.

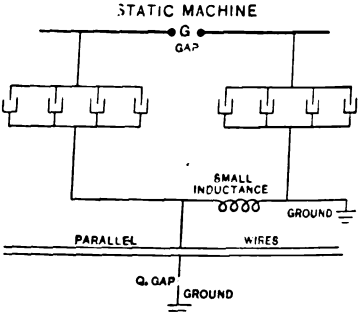


FIG. 7.

Experiments with Electrostatic Induction in Car Wiring. A test intended to show the intensity of electrostatic induction between medium lengths of parallel wires, without the intervention of electromagnetic induction is illustrated in Fig. 7. As a source of high frequency an electrostatic machine connected to leyden jars is used. The gap *G* of the machine determines the value of potential applied to the jars. On the right hand side, the jars are shown grounded, and on the left hand side the leyden jars are shown connected to 30 feet (9.14 m.) of straight wire; the middle point of this wire is connected through a small choke coil to the ground. A second straight wire is laid parallel and close to the first mentioned wire as shown in the figure and this isolated wire is connected to the ground through a needle gap marked *Q*. For any given length of straight wire it is intended to determine the relations of the potentials at the gap *G*, which represents the intensity of the lightning stroke, to the potentials at the gap *Q*, which results from the electrostatic induction, and further to note if the quantity in the discharge at *Q* gap is sufficient to puncture the usual kinds of insulations.

Results of the tests with the form of circuit shown in Fig. 7 are given in the table below. In general, it may be stated that the electrostatic induction through 30 ft. (9.14 m.) of wire is sufficient to give potentials of 20,000 to 40,000 volts, under the conditions described. Two choke coils were used, one of five turns of No. 6 B. & S. wire on a 4 in. (10 cm.) wooden core, and the other of twelve turns of the same dimensions. When the 12-turn choke coil was used, higher potentials were induced through the insulation between the parallel wires. When the value of the *G* gap was 3 in. (7.6 cm.) the electrostatic induction produced a spark of 1.2 in. (3 cm.) across the *Q* gap. The spark across the *Q* gap, which represents the insulation of the apparatus on the car, had sufficient brightness and strength to damage insulation.

TABLE OF POTENTIALS OF ELECTROSTATIC INDUCTION BETWEEN PARALLEL WIRES 30 FT. (9.14 M.) LONG

G gap inches	*Q* gap inches	Spark	Needles	Choke coil
1	0.416	snappy	small	5 turns No. 6 wire on 4 in. core
1⅜	0.532	"	"	"
2	0.625	heavy	"	"
3	0.92	"	"	"
3½	1.19	"	"	"
3½	1.32	"	large	12 turns No. 6 wire on 4 in. core.
3⅞	1.25	"	"	"
5	1.3	"	"	"
3	1.22	"	"	"
2	1.13	"	"	"
1⅝	1.05	less bright	"	"
1	0.84	"	"	"

UNUSUAL EXPERIENCE OF AN ELECTRIC RAILWAY SYSTEM DUE TO LIGHTNING STORMS

The middle and western portions of Colorado and neighboring States have always furnished an interesting field for lightning arrester installation because of the unusually severe disturbances which arise on all electric systems in these localities, due to lightning storms. The street railway systems have been unable to escape this condition, and the problem of preserving the continuity of service during thunderstorms in these localities has been a very difficult one.

The case of the Denver City Tramway, which operates the majority of the street cars in Denver, and also several interurban lines, is of exceptional interest because of the attention they have paid to the subject of protection and the results they have obtained along these lines. The storm conditions in Denver and vicinity are as severe, from the point of protection, as any that have come to the attention of the writers. Being situated about twenty miles east of the foot-hills of the Continental Divide, storm clouds which form over the mountains invariably pass over the city of Denver or its suburbs, and in this manner as many as two or three storms have been known to occur in one day. The duration of the storms varies anywhere from a few minutes to several hours, but frequently a storm of short duration produces as much damage, independent of its duration, as a much longer storm.

The Denver City Tramway operates over about 100 miles (160 km.) of streets within the city limits and about 50 miles (80 km.) of suburban lines. The rolling stock equipment at present consists of about 300 cars including work cars, etc. The majority of the cars are operated from one end only.

In years previous to the summer of 1909 this company waged an unceasing battle against lightning. They tried every commercial form of lightning arrester, and a number of experimental devices of their own manufacture, but in spite of all these endeavors to minimize the number of armature failures from lightning, they were forced, during the most severe storms, to entirely suspend the operation of the system. The circuit breakers at the power house and substations were always opened during severe parts of the storms. This interruption of power was a signal to all the car crews to pull down their trolley poles to prevent damage to motors from lightning. In this manner, the system has been known to be at a standstill at times for over an hour, which meant not only a large loss of revenue but a great inconvenience to the public at the time when the weather made it most important to have local transportation.

The suspension of service during the severest portions of storms seemed the wisest course, under the then existing circumstances, not only for the company but also for the public. The large number of cars that would have been disabled by operation during such times would have meant a severely crippled service for some time subsequent to, as well as during the storm. Also the problem of getting disabled cars to the repair barns is always aggravating even with few armature failures. If many cars were permitted to be damaged the service would be practically as effectively tied up, until the damaged cars were removed, as if the power had been turned off.

As already stated, every known type of lightning arrester either commercial or experimental, has been tried out to determine its merits, each car being equipped with sometimes as many as two arresters. One of the latest forms of arresters used is what is known as the water box arrester. This was installed on nearly all the cars and in the power house and substations. The form of this device used on cars consisted of a wooden tank about three feet deep, and a foot (30 cm.) diameter, which was filled about two-thirds full of water. A metal plate in the bottom of this tank was connected to the metallic car frame, and the top of the tank was provided with a carbon electrode which was connected to the cable passing from trolley base to the circuit breaker. The motorman was instructed to pull down the trolley pole and to lower this carbon electrode so that it was in good contact with the water at the approach of a lightning storm, and then to resume the operation of the car until the storm was over, or the power was discontinued at the power house. Besides failing to give adequate protection this arrester was a considerable inconvenience, due to the fact that after about one-half hour's operation it would begin to boil over.

Careful attention had been paid to the matter of line protection, and on some of the most exposed lines, arresters were installed at every trolley feeder tap. These taps are approximately 500 ft. (152 m.) apart.

Shortly after the first installations were made of the d-c. aluminum lightning arrester, this operating company obtained quite a number for installation in its power house and substations and also for installation on a number of the cars. The results obtained with these arresters during the summer of 1909 were so promising as to lead to the equipping of the entire system with d-c. aluminum lightning arresters. Early in the summer of 1910, the work of installing the arresters on the cars was started. The type of arrester installed was the standard 600-volt d-c. aluminum cell lightning arrester. This arrester has no series gap nor any series resistance, thus, it is connected directly between the trolley and ground through a 25-ampere fuse. Balancing resistances are used in parallel with the two cells to prevent unequal distribution of potential across them. Fig. 8 illustrates the arrester used, while Fig. 9 shows an arrester installed in the motorman's vestibule.

When the water box lightning arresters were installed they were located in the motorman's vestibule at the No. 1 end of the car. Since this location was the most accessible place in the car the new arresters were installed in the same place. In the case of the old arresters a loop from the trolley pole base had been run down inside the motorman's vestibule through a choke coil, then to the top of the vestibule again, into the circuit breaker. This same loop was used when the new arresters were installed, and is shown in Fig. 10. The ground connection for the arrester was made as short as possible by connecting to the nearest piece of the metallic frame of the car. Another ground connection was run directly to the frame of the motor.

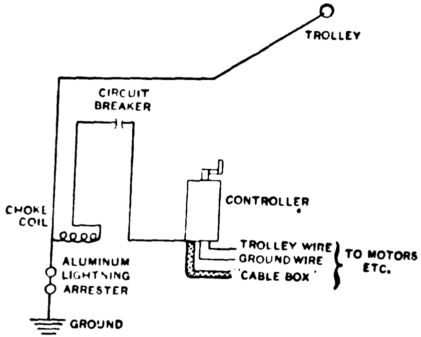
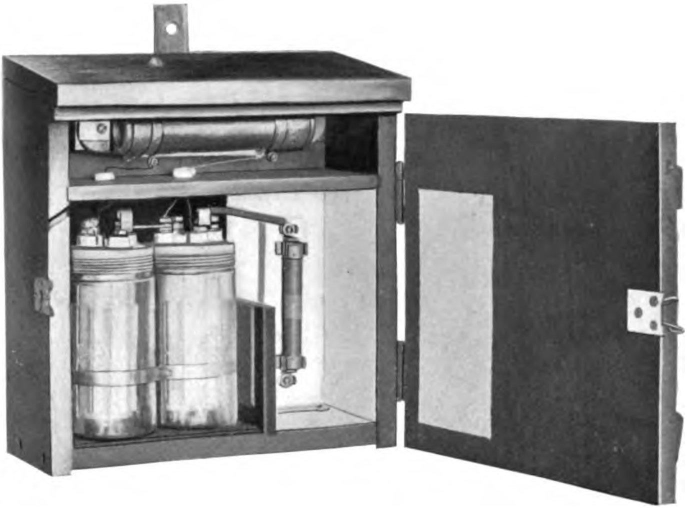


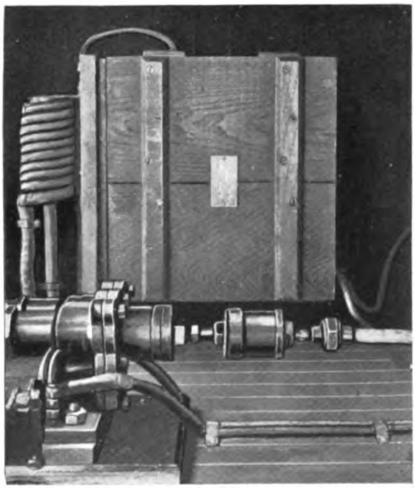
FIG. 10.—CONNECTIONS FOR ALUMINUM LIGHTNING ARRESTER AND CHOKE COIL.
As Installed on Single End Operated Cars of the Denver City Tramway Co.

In some of the older types of cars only one circuit breaker was used, or the two circuit breakers were in series and consequently the trolley bus to the controller in the No. 2 end of the car ran through the cable box. To minimize the induction between this trolley wire and also between the ground wire, and other wires in the "cable box," these two wires were removed from the cable box and placed as far from it as the conditions would permit.



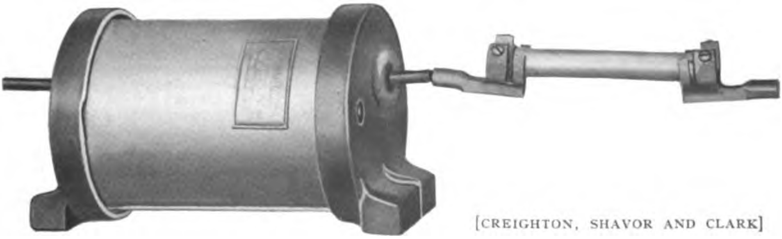
[CREIGHTON, SHAVOR AND CLARK]

FIG. 8.—1909 MODEL OF 600-VOLT DIRECT-CURRENT ALUMINUM LIGHTNING ARRESTER, SHOWING ARRANGEMENT OF PARTS.



[CREIGHTON, SHAVOR AND CLARK]

FIG. 9.



[CREIGHTON, SHAVOR AND CLARK]

FIG. 14.—NEW TYPE OF MAGNETIC BLOWOUT LIGHTNING ARRESTER.
Assembled View, Showing Series Resistance.

The power house and substation lightning arrester equipments were brought up to date by the installation of an aluminum cell arrester on the panel of each outgoing feeder, and in the case of the power house, an aluminum cell arrester was also placed across each generator.

The number of arresters on the trolley line was increased by the addition of all the serviceable gap arresters which were removed from the street cars.

The following table gives a fairly complete summary of the operation of the system during the years of 1909, 1910 and 1911.

Comparative Table

Storms	1909	1910	1911
U. S. Weather Bureau Report*	52	39	31
Cars			
Total number (approximate figure)	279	279x	304
Average No. of cars in operation (approximately)	170–250	170–250	170–250
Cars re-wired	0	193	193
Cars not re-wired	279	86	more than 86
Cars equipped with direct-current aluminum lightning arrester	65	278	304
Cars not equipped with direct-current aluminum lightning arrester	214	1	...
Cars reported with armatures damaged by lightning	102	2	1
Cars protected by aluminum arresters damaged	8	1	1
Cars protected by aluminum arresters damaged (in per cent.)	12 per cent.	0.36 per cent.	0.33 per cent.
Otherwise protected cars damaged	94	1	...
Otherwise protected cars damaged (in per cent.)	43.9 per cent.	100 per cent.	...

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* The United States Weather Bureau Report of thunder storms gives only a record of the number of days during the year on which thunder was heard by the station observer. Two storms occurring on the same day would consequently be reported as one, while a single thunder clap would be reported as a thunder storm. Although this report gives a smaller number of thunder storms occurring during 1911 as compared to the two previous years, that season as a whole was unusually severe from the standpoint of lightning disturbances. The storms were, in the opinion of several experienced engineers, as severe as had been encountered during several seasons past.

During the year 1910 new cars were being gradually placed in service and consequently the total number of cars for the year was variable.

According to the above table, during the year 1909 the proportion of cars protected by aluminum arresters which were damaged by lightning was 12 per cent, as compared to the 43.9 per cent of the otherwise protected cars which were disabled from the same cause. During this season, the service was intentionally interrupted a number of times during the most severe portions of several storms.

For the year of 1910 the storm conditions were not considered as severe as during the year following. There were no suspensions of service because of lightning, and only two cars had armature failures from this cause. One of these cars was the only car on the system which was not protected by the aluminum lightning arrester.

During the year just passed, 1911, the storms were very severe, as stated above, but during that time only one car suffered armature failure from lightning. There were no suspensions of service even during the most severe storms. In one instance, on an interurban line, lightning shattered three poles supporting the overhead trolley wire and a car passing at that moment suffered only a damaged arrester.

At the time that the protection of the apparatus of this system was undertaken by the installation of the aluminum lightning arresters, the protection of cars, in light of past experience, seemed so difficult, that every known precaution was taken in the installation of these arresters on the cars. Besides making the lightning arrester circuit as short as possible and providing double grounds the car wiring was rearranged on a majority of the cars. This re-wiring as has been mentioned previously, consisted in the removal of the trolley bus, when such existed under the car, from the so-called cable box, to a position as far removed from the cable box as possible. The ground wire was treated in a like manner, the trolley bus and the ground wire generally being placed together.

There is no better evidence of the coöperation of Mr. John Evans and Mr. W. H. McAloney, respectively, chief engineer and superintendent of rolling stock of the Denver City Tramway, than is shown by their willingness to take this precaution of re-wiring the cars, an entirely new procedure, entailing considerable expense.

The uniformly satisfactory results obtained with all the cars during the years of 1910 and 1911, make it impossible to draw positive conclusions from the records of these two years as to the effects of this re-wiring.

The experience during the year 1909 is noteworthy, however, in that it apparently demonstrates that the re-wiring was a valuable improvement. The foregoing table shows that during that year 12 per cent of the cars protected by aluminum arresters were damaged, whereas, during the two succeeding years, with a majority of the cars re-wired, less than 0.4 per cent of the cars protected by aluminum arresters were damaged, in spite of the fact that they were operated continuously through every storm.

This evidence would be positive enough if it were known that all the aluminum lightning arresters on the cars were in normal condition. There is a possibility, however, that on some of the eight cars protected by aluminum arresters which were damaged in 1909, the arresters had lost a portion of their electrolyte, with a consequent reduction in their protective quality.

The resulting benefits obtained by the installation of the d-c. aluminum arrester may be briefly summarized as follows: Motor failures due to lightning have been decreased to an almost negligible value, and this means a decidedly lower maintenance charge. The reliability of service has been increased many fold during the years of 1910 and 1911, no interruptions chargeable to lightning having occurred during these years.

The cost of installation and maintenance of the arresters in this particular case is more than offset by the decrease in maintenance of motors and increased revenues, due to continuity of service during thunderstorms, to say nothing of the increased good will of the public who could not understand the justifiable reasons for being discommoded by an interruption of car service.

Choice of the Type of Lightning Arrester

In the foregoing, the demonstrations have been conclusive that the d-c. aluminum arrester gives next to absolutely perfect protection against lightning. The application of the arrester directly connected is to be recommended wherever the lightning is severe and where the service is important. A particular example of railway service where the arrester, directly connected, is advisable without consideration of other factors, is electric locomotives. The first cost of a locomotive warrants a considerable outlay in any protective device that will give a reasonable insurance against damage to the insulation and thus prevent stalling of a train en route. Putting aside considerations of lightning, heavy current traction involves greater electromagnetic surges and, consequently, greater risks of flash-overs on the commutators. The aluminum arrester has proved very effective on synchronous converters in preventing flash-overs and should be equally effective on a motor. In generating stations and substations, again, the advisability of using the aluminum arrester, directly connected, can not be questioned. There are conditions, however, where the application of the arrester in its present form is not beyond question. The reasons for this and the location will now be considered.

Where the aluminum arrester is directly connected there is a constant leakage current of about one thousandth of an ampere, consuming about one half a watt, which after a year or two produces an appreciable wear on the aluminum plate. Finally the aluminum film gets in such a bad condition that the electrolyte is boiled out. It is then necessary to obtain more electrolyte and usually to renew the aluminum plates. When the plates become old, more inspection is required to locate the empty jars as soon after they become inoperative as possible, so as not to leave the car without protection. Where lightning troubles are not frequent, operators are loath to give the arresters the desirable inspection and undertake the expense of renewals. There is then a field of application where much depends on the local conditions and the attitude taken by a railway company. This may be considered a border line where the practise is questionable. Across the border are situations where the best engineering dictates the use of the gap type. The protective devices installed along the trolley line for protection against lightning should surely be (in the light of present information) of the gap type. The reasons for this will become apparent when the functions of the trolley line arrester are taken into consideration. The use of the trolley line arrester is to relieve local strain on the line, and thus, lessen the duty of the car arresters. The length of the lightning arrester circuit from the trolley over to the pole down to the ground and back to the rail is unavoidably long. Furthermore, the distance of any car from such an arrester is, in general, considerable. Therefore, the presence of the series gap is less objectionable than it is on the car arrester. Also, since the line arresters are without attendants, the use of an arrester requiring specific inspection is an uneconomical condition.

The foregoing statements regarding the line arresters apply specifically for the protection against lightning. When it comes to a matter of protecting against electromagnetic surges and "flashing" around the commutator, the gap type of arrester, in the present stage of development, is not efficient.

Addition of the Vacuum Gap, and Charging Gap to the D-C. Aluminum Arrester. Under the previous heading an endeavor was made to analyze the different conditions to be met and the characteristics of the aluminum arrester which limited its application. Devices will now be described which widen the application of a d-c. aluminum arrester. As already stated, it is continuous application of potential to the aluminum cells which causes the wear, and thus, shortens their life. A very occasional charge will keep the films on the aluminum plates in good condition. Leaving this charging operation to the daily attention of the inspector is out of the question, under the conditions which exist at the present time in the usual car barn. This calls for some automatic device. A charging gap is used which automatically closes the circuit from time to time when the car is in use.

In order to meet the condition of partially dissolved film, which occurs after an arrester has been left disconnected for several weeks, a limiting resistance is placed in series with the charging gap. The drop of potenial across this resistance is negligible when the film is in good condition, but otherwise the resistance absorbs enough of the potential to reform the film slowly enough to prevent overheating of the electrolyte.

The use of the charging gap necessarily involves the use of a series gap in a lightning arrester circuit. An old problem in lightning arrester design reappears. A large gap has an objectionably high spark potential. A small gap brings down the spark potential but the gap is very easily short circuited by the splashing of molten metal from the crater of the arc across the gap. We have had this problem up for solution in the protection of apparatus operating at 100 volts or less, and have been able to produce an arrester with a gap about a millimeter long with a spark potential range anywhere from 500 volts up. This arrester will be described elsewhere. The spark potential chosen for the gap may be either a little above or a little below the potential of the trolley. If the potential of the gap is a little below the trolley potential then an occasional discharge will take place across the gap when the charge in the arrester leaks out sufficiently to bring the difference of potential between the arrester and the trolley to a value equal to the spark potential of the gap.

The phenomenon taking place here is simple. The aluminum cells take a charge like an ordinary electrostatic condenser, and maintain a proportional potential so long as the charge is there. The charge gradually leaks through the film. An arrester in good condition may require several minutes to lose its charge entirely.

Unfortunately, this device can not be used for keeping the film in good condition, as the gap never allows the arrester a charge of full trolley potential. If the spark potential of the gap is set slightly above trolley potential, there is more safety in the operation of the arrester, and very little difference in the protective value. As already stated, the introduction of this gap in series with an aluminum arrester will decrease its protective value by an amount which is yet unkown. Since the spark potential is only slightly above trolley potential, the objection to the gap lies in the unknown value of the dielectric spark lag. Applications of these devices have been made, and information is being gathered at the present time.

The use of the charging gap for the aluminum arrester broadens its field of application. It will become applicable to many cases where lightning is comparatively rare. The engineering practise as a whole is tending towards better car protection, and less protection on the line. This condition is going to be the chief justification for the extra expense and extra trouble that is involved in the use of the aluminum arrester. The chief object is to keep cars moving. One aluminum arrester well installed can save its cost many times over by the decrease in the number of line arresters required.

A summary of recommendations will be given later.

MAGNETIC BLOW-OUT TYPE OF ARRESTER

The original magnetic blow-out type of arrester was invented by Prof. Elihu Thomson. The design in present use was put in an efficient form by Mr. E. M. Hewlett and so long as the application was limited to potentials of six hundred volts no improvement was found feasible. The increases in trolley potentials to 1200, 1800, and 2400 volts direct current, however, taxed the arc extinguishing device of a single arrester beyond its limit and it was necessary either to place two or more arresters in series or reconsider the elements for a new design. It is the theoretical and experimental treatment of these factors of design that it is desired to give in this subdivision of the paper.

There are certain elements fundamental to the arrester which are intrinsically essential to the new design. These essential elements are: A gap with a magnetic field perpendicular to it; a slight amount of series resistance, especially where a battery is used on the circuit, to limit the dynamic current to a value less than a short circuit when a discharge takes place across the gap; and an arc chute to direct and help extinguish the arc.

In the older designs the magnetic field was produced by means of an electromagnet shunted across part of the series resistance as shown in Fig. 12. When this arrester failed to extinguish the dynamic arc it was usually due to the loss of the magnetic field. The insulation of the coil of the electromagnet had necessarily a limit and when the lightning produced a drop of potential across the coil beyond this limit, the coil was shunted out by a spark. With no magnetic field to cause the arc to rise, it remained in the gap and the current continued to pass through the arrester until the energy loss in the resistance rod in series overheated it and a short-circuit resulted. From the information collected failures of this nature have been relatively infrequent.

In place of an electromagnet is a permanent magnet in the new design. Long pole pieces are placed on the magnet to give a better directed and concentrated field in the path of the arc. The arc is made to play into the loop formed by the steel of the magnet and thus gives the maximum remagnetizing effect at every discharge. As an experiment an arrester was made to magnetize its magnet from a slight amount of residual magnetism. This was done by the first discharge. There are very important advantages that a permanent magnet has over an electromagnet, aside from the elimination of the relatively weak insulation of the coil. One of these advantages is connected with the choice of gap length, and will be described under that heading.

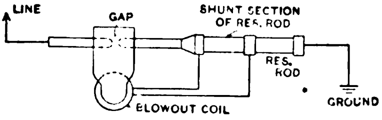

FIG. 12.

Gap-length. For the protection of 600-volt apparatus it is naturally desirable to have the spark potential of the gap as little above 600 volts as practicable. In the older form of arrester it was found undesirable to reduce the gap to much less than 25 mils (0.025 in.) (0.635 mm.). This is a little less than 1/32 in. The minimum value of gap setting was determined mostly by the tendency to splash molten metal from the crater of the arc across the gap and thus permanently short-circuit it. The magnetic field around the gap was not strong enough to lift a molten metal bridge out of the gap. There is another factor in the older design that magnified this effect and, furthermore, made it more difficult to pull the arc out of the gap into the arc chute. This factor consisted in the formation of an arc crater on the electrodes before the magnetic field appeared in the gap. The magnetic field coming from an electromagnet is dependent on the establishment of a current in the coil. The time constant of the coil delays for a brief moment the appearance of the magnetic flux. As the summer time goes, this delay is infinitesimal but in the time required to form a crater it is nearly a lifetime. The formation of a molten crater on the tips of the electrodes has two effects. First, it wears away the points of the electrodes and varies the gap-length; second, it requires more magnetic force to move an arc that terminates in a stable molten crater. When a permanent magnet is used the magnetic field is always present. The arc begins to move as soon as it appears, leaving no time for the formation of a definite crater. With this new condition it is immediately practicable to effect two important changes in the design of the arrester: the mass of metal in the electrodes can be reduced and the electrodes, no longer subject to wear at the gaps, can be fixed once for all with a definite minimum gap setting between them. Furthermore, in the absence of a molten crater, it is permissible to reduce the gap setting. Good results have been obtained with a gap of fifteen mils (1/64in.) (0.381 mm.)

The Cut of the Electrodes. Although apparently only a minor detail, the angle of cut of the electrodes from the point upward has an important bearing on the successful operation of moving the arc out of the gap. Experiments demonstrated that with the available magnetic force an angle as large as 40 deg. from the vertical at the end of the electrode caused the arc to stick at the point. An angle of less than 10 deg. was too much on the other side and also produced burning of the electrodes at the points. A full discussion of this feature and the several factors involved is perhaps too detailed to fall within the scope of this paper.

The Arc Chute. The form of arc chute was the subject of exhaustive experiments. At potentials above a thousand volts the form of the arc chute is of prime importance. In the older forms of arrester the arc chute is rectangular, having the dimensions: 25/32 by 1⅛ in. (19.8 by 28.5 mm.) at the top, 7/16 by 21/32 in. (11 by 16.6 mm.) at the bottom, and 2¼ in. high.

The arc is thus constrained to take the form of two parallel streams as it is thrown out by the magnetic field. Even at 600 volts it shoots out beyond the arc chute several inches. At higher potentials, and also at heavier currents than normal, the two arc-streams repeatedly break into each other which shortens the arc and thus prevents it from attaining a length sufficient to extinguish itself. The natural tendency of the magnetic field is to open the arc into an arch or loop and the first requirement in a new design is to lengthen the arc chute so the loop can be opened sufficiently to prevent the potential from striking across as the arc is lengthened.

The lengthening of the arc chute is carried down to the lower part at the electrodes. This allows the arc to run back along the electrodes and the craters are formed at spots on the electrodes where burning will do no particular harm.

The next dimension to be determined is the width of the arc chute. Narrowing down the arc chute flattens out the moving arc and by exposing a large surface to the cooling contact with the walls of the chute, chills it and thus aids and hastens its extinguishment. There is, however, a minimum width below which the arc will not be extinguished. This minimum width is reached when the friction of the arc against the walls of the chute becomes so great that the available force from the magnetic field is unable to move the arc rapidly up the chute. Any further restriction causes the arc to hold across the electrodes.

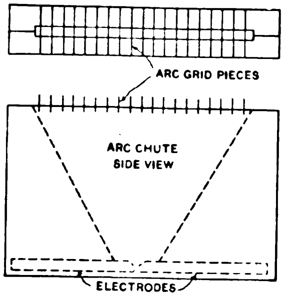

FIG. 13.

The Lower Aperture of the Arc Chute. It is necessary to leave an air vent at the lower end of the arc chute to prevent the formation of a partial vacuum back of the moving arc. Without such a vent the air pressure in front of the arc will stop its progress up the chute and the walls of the chute will, consequently, be melted by the intense heat of the arc.

The Arc-grid. If the arc chute is made high enough the arc may be extinguished in the chute. For use with potentials above a thousand volts, the arc chute becomes ungainly in height. Therefore another device is added to aid and complete the extinguishment of the arc. It consists of many metal plates laid on their edges at the top of the arc chute, and perpendicular to the chute. These metal plates are insulated from each other and spaced a fraction of an inch apart. (Fig. 13.) When the arc rises out of the chute it is broken up into as many parts as there are spaces between the plates of the grid. The grid becomes, in effect, a multiple gap arc extinguisher. In these gaps two effects are present. First, the arc is cooled by contact with the cool metal of the grid, and second, each arc absorbs 45 volts or more at its electrodes. Forty-five volts is the minimum potential that can establish an arc, therefore if there are fifteen plates in the grid the arc can not be established between the plates of the grid. Incidentally it may be of interest to note that the effect of this multigap arrangement differs from its usual application to alternating currents. While in direct currents the e.m.f. available for extinguishing the arc is only the potential of the arc, in alternating currents the arc is extinguished naturally at the end of the half cycle and it becomes a matter, not of maintaining an arc, but of reestablishing an arc in the reverse direction in the partially cooled vapors. According to the circumstances, to reestablish the arc requires a potential running up into the hundreds of volts.

By using a grid consisting of sixteen plates or more in an arrester designed for 600 volts direct current an arc will be entirely extinguished by the grid and will emerge in the form of heated but de-ionized gases. These gases are passed around to the bottom of the arc chute again; thus it is no longer necessary to have the arc discharge into the open. The arrester is, consequently, enclosed and requires no containing box of wood.

Series Resistance. The mechanical conditions call for a resistor of dimensions as small as practicable. The electrical conditions of protection call for as low an ohmic resistances as practicable. Between these two requirements the resistance rod becomes the first part to fail if the current, due to some accidental condition, is not interrupted. This is one reason why the rod is placed outside the metal-porcelain containing box. Another reason for placing the rod outside is for ease of inspection. It is aimed to have the design such that an inspector may be assured that the arrester is in good condition if the resistance rod is intact. Since the arrester is designed especially for line use, it can be inspected in such a position from a trolley car running at full speed. Still another reason for placing the resistance rod externally is to insure, in the few cases of accidental damage, that the circuit can be immediately cleared. One of the most disastrous things to the service is to have a persistent short circuited line arrester in an enclosed box on a section of a trolley and be compelled to inspect each individual arrester to locate and remove the trouble.

Although the new arrester has an ample factor of safety in the design it is desirable to allow for extreme and untoward conditions by so constructing it that a persistent short-circuit after the circuit breaker has gone out is impossible. This is accomplished by choosing a resistance rod such that a persistent current through it will overheat and crack it into pieces. On the other hand, the rod will withstand many successive discharges without damage. A single discharge on a 600-volt circuit raises the temperature about 3.5 deg. cent. when the arrester has a 5-ohm series resistance. It is proposed, then, to place the rod out in the open when the arrester is installed on a pole. When installed on a car, however, the rod is to be placed in a porcelain tube in order to insulate it against any possible contact with persons.

Summarizing, a new design has been made of a higher potential arrester involving a shorter gap length, a permanent magnet that prevents burning at the electrodes, a narrow long arc chute presenting a large cooling surface to the arc, an arc-grid of metal to insure entire extinguishment of the arc, and a return path for the gases. All these parts are entirely enclosed and a resistance rod is placed externally in series. See Fig. 14, Plate XLIV.

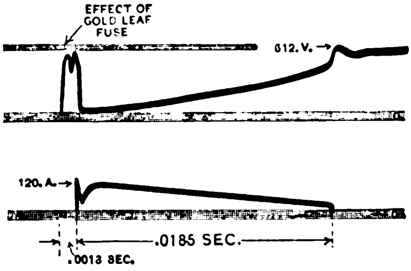

FIG. 15.

Oscillographic Studies. Some oscillographic tests are given to illustrate the exact relations of current, potential, and time in the arrester. The first group of oscillograms illustrate the early stages of the development when the effect of the form of the arc chute, strength of magnet, etc., were being determined. The second group of oscillograms were taken on the arrester in its final form.

Oscillogram Fig. 15. This oscillogram is selected to show especially an incidental phenomenon of the test, namely, the effect of poor contact of a strip of gold leaf placed in the gap of the arrester to start the dynamic current. On the potential vibrator, which is the upper record, the potential rises to about 600 volts when the main switch is closed, it then drops slightly, rises again, and then drops back to about 50 volts. Fifty volts is the potential of the arc of 120 amperes as it is first established in a 15 mil (0.038 mm.) gap. It should be noted that the current does not start until the instant of drop of potential to 50 volts. This is more than a milli-second after the potential is applied to the fuse of gold leaf. Although this delay of the establishment of the dynamic current has no practical significance the length of the delay is remarkable.

As a further comment it required 18.5 milli-sec. to extinguish the arc. During this time the arc was being gradually driven up the arc chute and thereby lengthened; the record of the voltage shows that the potential of the arc rose correspondingly to about 500 volts and then as the arc was suddenly extinguished rose quickly to trolley voltage. Further comments on the details are reserved until the next oscillogram where they are shown on a larger scale.

Oscillogram Fig. 16. Walls of arc chute of asbestos. Gap length is 15 mils (0.038 mm.) Resistance in series is 1.7 ohms. Angular cut of electrodes is 15 deg. (Fig. 17). Height of arc chute 3.5 in. (8.89 mm.), length of arc chute 2.5 in. (6.35 mm.) Width of arc chute about $\frac{1}{4}$ in. (6 mm.) at outer end.

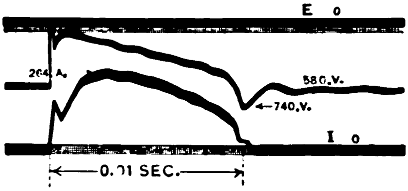

FIG. 16.

The upper record is the voltage across the gap alone. The lower record is the dynamic current through the arrester gap. The voltage terminals of the oscillograph happened to be reversed relative to the current vibrator terminals.

Characteristics of the Current Curve. The form of the current curve is typical of all the tests made in the laboratory on the city trolley circuit. The current rises suddenly, drops back relatively slowly, then rises slowly to a maximum. An exact explanation of this is not known. It seems that the first rush of current comes from the stored energy in the near part of the trolley (the laboratory is about a mile from the power house.) Since we would scarcely expect to find so much stored energy in the electrostatic field of a 600-volt circuit, we might look for the stored energy in car motors. After the drop back in the current, the gradual rise on the main part of the wave is evidently due to the choking effect of the inductance in the rails and trolley, and also in the generator. The time constant of this circuit is approximately 1.5 milli-seconds to 2 milli-seconds. The current never reaches its ***maximum possible*** value because as the current rises the arc is being drawn out by the magnetic force and is gradually absorbing the potential. When the current reaches its maximum (in about 3 milli-seconds), the potential across the arc has already risen to over 180 volts.

Characteristics of the Voltage Curve. The spark in this test was started by the discharge of an induction coil. As remarkable a thing took place as in the previously shown oscillogram when the arc was started by means of a gold leaf fuse. The potential across the gap drops suddenly to approximately zero. While the current is rising suddenly to 160 amperes, (about 0.2 milli-seconds) the arc does not apparently form. At the end of this time, however, the arc suddenly assumes a potential of 230 volts, and gradually drops back to about 100 volts before it again begins to rise. An explanation of this is not evident on the face of it. Apparently the explanation is as follows: At the first instant the spark from the induction coil starts the dynamic current but the spark cannot form into an arc because a strong magnetic field is moving the spark up the cut of the electrodes so rapidly that no spot is given sufficient heat to form a crater. Without a crater no metallic vapor is formed. The characteristic of an arc is the electric conduction by the vapor of the electrodes. A spark, which is heated air, is the conductor in this case. It has dead resistance but no appreciable apparent counter e.m.f. similar to the drop of potential at the

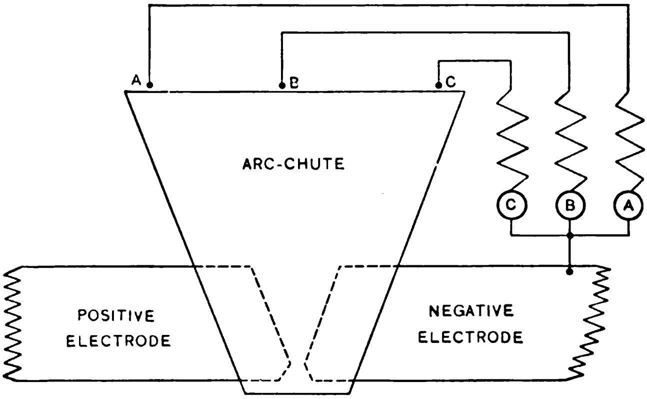

FIG. 17.

positive electrode of an arc. As soon as the spark is lifted out of the 15 deg. angle of the electrodes its terminals are carried more slowly horizontally along the electrodes and there is time given to heat the copper at a spot to the melting temperature and consequently the arc appears.

With a current of more than 100 amperes flowing when the arc potential first appears it is not at all evident why the initial arc potential should be as great as 230 volts. An attending circumstance is a decreasing value of current at this time. When an arc is formed by a gradually increasing current the potential starts high and diminishes as the current increases but here is a case where the current is high and simultaneously the potential across the arc is also high. The question arises—what has become of the conducting gases of the spark? No matter what scientific explanation is given to this phenomenon, there is one practical result of great value in the operation of the lightning arrester: there is not the slightest indication of burning at the sharp points of the electrodes due to the discharge.

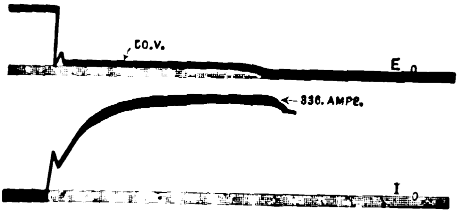

FIG. 18.

Commenting on the later part of the voltage curve, the potential rises uniformly in a most desirable manner until the arc current drops to about 80 amperes. At this time the potential across the arc is nearly full trolley potential and the arc becomes unstable and flicks rather suddenly. As the arc is extinguished the surge of electromagnetic energy raises the potential of the trolley to 160 volts above its normal value. While there is no harm in this small rise it is an indication that it is possible to make the design such as to greatly magnify this value. At the time these tests were made it seemed undesirable to reduce the total time of the arc below 4 milli-sec. It is not a question of strain on the insulation by this rise of potential so much as an increased risk of starting a "flash" around the commutator of some motor in the neighborhood. The final design must exclude this objectionable feature.

Incidentally the oscillogram shows that the natural period of oscillation of the trolley system is about 3 milli-sec. or in terms of the frequency, 333 cycles per sec. This is shown by the oscillation in the potential curve after the current is reduced to zero.

Oscillogram Fig. 18. This oscillogram is given to show especially the bad effect of large angular cut of the electrodes. In the previous oscillogram the cut of the electrodes was 15 deg. from the vertical. In the present oscillogram the only change is to a cut of 38 deg. to the vertical. The result was that the arc was not extinguished by the arrester and the circuit breaker in series finally opened the circuit. The electrodes were very badly burned at the points showing that the arc did not rise.

Comments on the Current Curve. Again the characteristic rise of the current in the d-c. circuit at some distance from the power house appears. In this case the current was not limited and it rose to its full value of 336 amperes. The light of the vibrator was cut off before the circuit was opened, therefore the curve is shown incomplete,—that is to say, it does not return to zero.

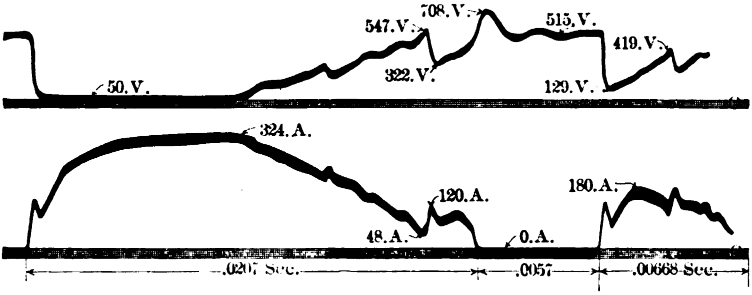

FIG. 19.

Comments on the Potential Curve. The beginning of the potential curve differs considerably from the one given in the previous oscillogram. The potential does not drop to zero when the current starts, but maintains its full value for a brief period, then drops to a low value and rises as the current drops back after the first current rush. The potential then drops to approximately 50 volts and retains its value constantly showing that there was no elongation of the arc.

Oscillogram Fig. 19. This test is a repetition of the previous test. New electrodes were placed in the arrester with the same

38-degree angular cut from the vertical. The objectionable feature of this large angle at the electrode is again represented in this oscillogram, although the arc was finally extinguished after the second trial.

General Comments. The voltage curve at the start is again different from all the preceding oscillograms. In this case the voltage drops rapidly at first and then gradually to 50 volts without any reversal on the way. It will be noted that in this case again the arc sticks in the electrodes and the potential remains about 50 volts for nearly 10 milli-sec. The arc, however, is shifted out of the electrode, although it sticks back along the electrodes several times in rising. Finally after about 21 milli-sec. the arc is put out. After about 6 milli-sec. more of zero current there was evidently a second, and accidental, discharge from the induction coil starting the arc again across the gap. Since the electrodes were already burned back the arc was extinguished the second time much easier than the first time. The light on the film was cut off the voltage vibrator a little bit early, and, therefore, the record is not complete back to trolley potential. This oscillogram shows a bad condition both for the electrodes and the arc chute. The condition of the arc chute was not brought out in the previous oscillogram.

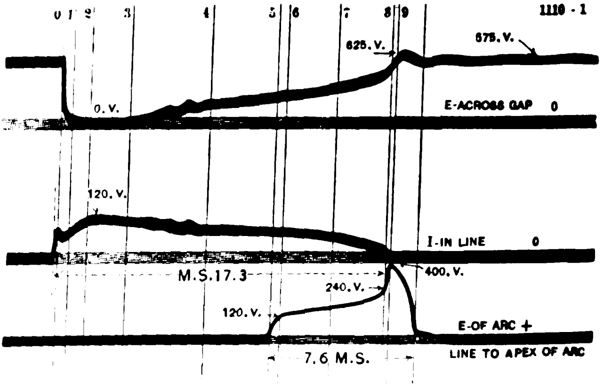

FIG. 20.

Oscillogram Fig. 20. A resistance of 6.7 ohms were in series and the angular cut of the electrode was 5 deg. It will be noted that the arc stuck between the electrodes for a considerable time. In this case the trouble was due not to the angular cut of the electrode so much as to the lack of force from the magnetic field of the arc. It will be noted that by an increase in the series resistance the current has been materially reduced and the force on the arc is directly proportioned to the value of the current. In this case it required 17.3 milli-sec to extinguish the arc.

In this stage of the development the value of allowing an air vent under the electrodes was not fully appreciated and it may be that this factor is also involved in holding the arc in the gap longer than desirable.

A third record is shown in this case to determine the time of rise of the arc in the arc chute. A voltage vibrator was connected with one terminal to the negative electrode, and the other terminal was connected to the platinum wire shown at *B*, Fig. 17, which was laid across the outside of the arc chute directly above the electrodes. The distance was 3¼ in. (82 mm.) from the electrodes to the platinum wire. It required 11½ milli-sec. for the arc to reach this platinum electrode. It will be noted also that after the series current in the arrester ceases there still remains an arc from the positive electrode to the platinum wire. These hot gases remain conductive to the 0.1 ampere taken by the voltage vibrator for 1.3 milli-sec. after the main arc has been interrupted.

Cross lines are drawn on this oscillogram to relate the records to equal time. The following list is given of the time relations:

From line 0 to line 1 the voltage drops to the arc value or practically zero in 0.6 milli-sec. The voltage remains at this low value for 3.1 milli-sec. At crossline 2 the current rises to 120 amperes. In the time between the cross lines 3 and 5 the current gradually drops and the voltage rises. Cross line 5 is timed when the arc strikes the platinum electrode and is 11.5 milli-sec. from the beginning. Between cross lines 5 and 6, which is 0.4 milli-sec., the arc potential at the platinum rises to 120 volts above the negative electrode. In other words this is the drop of potential from the middle of the arc to the negative electrode. At the crossline 8 the main current is reduced to zero and the voltage from the platinum electrode to the negative terminal constantly rises from 240 volts to 400 volts. The rest of the 575 volts of the trolley, that is 175 volts, is the drop in potential along the arc from the platinum wire to the positive terminal. The time between cross lines 8 and 9 is 0.2 milli-sec. After the main current ceases, the arc vapor between the positive electrode and the platinum exploring wire gradually cools as the tenth of an ampere taken by the oscillograph is not sufficient to maintain the vapor conductive. This arc gradually absorbs the voltage away from the oscillographic voltmeter and reduces the voltage to zero. This requires 1.3 milli-sec.

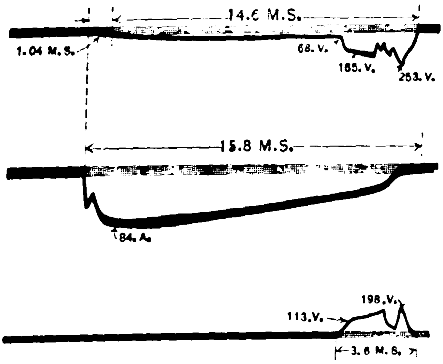

FIG. 21.

Oscillogram Fig. 21. A series of tests was subsequently made to determine the position of the arc relative to the electrodes and arc chute, at every instant. It is thought that the details of this study are too much involved to be of general interest, and therefore these oscillograms are omitted. Oscillogram, Fig. 21, however, is given to show two positions of the arc. This illustrates the method of study.

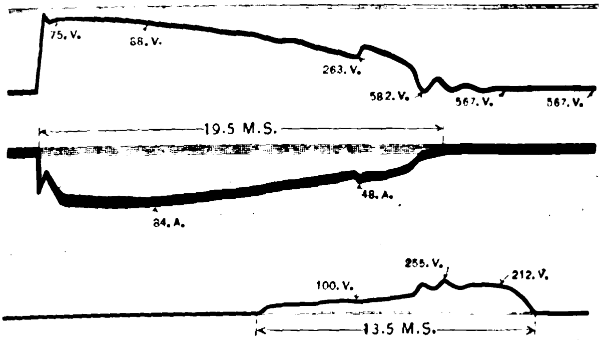

FIG. 22.

The platinum exploring electrodes were located at the points *A* and *B*, as shown in Fig. 17. *A* is at one end of the arc chute over the positive electrode and the point *C* is at the other end of the arc chute over the negative electrode. In both records 1 and 3 on the oscillogram the other vibrator terminals are connected to the negative electrode. These exploring voltage vibrators then measured the drop of potential from *A* to the negative electrode along the arc, and *B* to the negative electrode along the arc, so long as the arc was complete between the positive and negative electrodes.

Oscillogram Fig. 22. Subsequent to the last oscillogram, carbon electrodes were laid on top of the copper electrodes in such a way that after the arc was raised out of the gap the craters formed on the carbon. This carbon arc was more difficult to extinguish than the copper arc. With all conditions the same, the time was increased from 15.8 to 19.5 milli-sec.

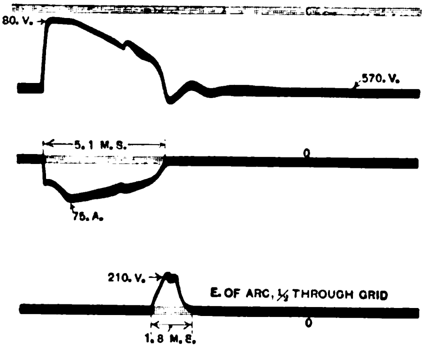

FIG. 23.

Oscillogram Fig. 23. In this oscillogram a metallic grid was used over the arc chute to aid in extinguishing the arc. In order to determine how far through the grid the arc penetrated, the platinum electrode at position *B*, Fig. 17, was inserted half way through the grid. The arc reached this electrode, as shown in the lower record. The resistance in series 6.6 ohms. The arc was extinguished in approximately 5 milli-sec. One small irregularity in the decrease of the current is shown, but the arc was extinguished without any heavy surge in potential.

The grid consisted of 17 pieces of flat copper sheet spaced $\frac{1}{8}$ in. (3.2 mm.) apart. The depth of the grid was $\frac{7}{8}$ in. (22.2 mm.) In the lower record the other terminal of the voltage vibrator was connected to the positive electrode. The fact that the current persisted in this vibrator after the main current had been reduced to zero shows the persistence of the vapor at positive electrode even after it is cooled at the negative electrode.

Oscillogram Fig. 24. This oscillogram was taken with slight improvements in the arc grid and the arc chute. The resistance in series were the same as in the previous case. Decrease in current and change of potential are satisfactorily uniform. The exploring electrode of platinum was placed just below the top of the arc grid. The absence of any curve on the lower vibrator indicates that the arc did not reach the exploring electrode.

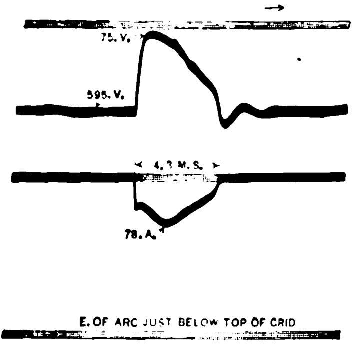

FIG. 24.

Oscillogram Fig. 25. In contrast to the oscillogram Fig. 24 where the operation of the arrester was satisfactory, this earlier oscillogram is given to show an improper design of arc chute and auxiliary devices. In this oscillogram the arc chute was shortened and a metallic ladder placed up the side of it. The arc chute was so short that as the arc rose into an arch it kept restriking across a shorter length for a considerable time. This is a condition that never exists in a normal arc chute of porcelain, and shows the impracticability of using a metallic ladder in the arc chute under the conditions tried. The duration of current was 35 milli-sec.

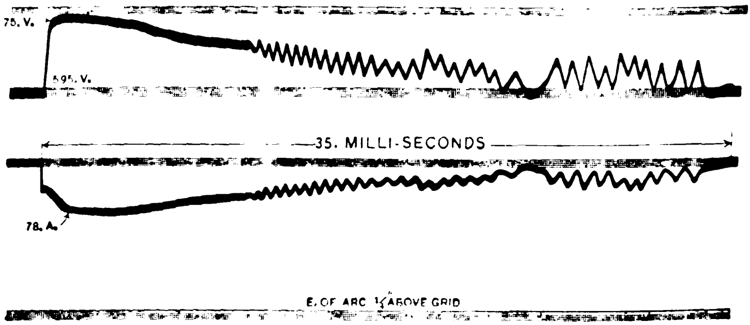

FIG. 25.

Oscillogram Fig. 26. Discharge of a lightning arrester on 1,790 volts direct-current,—lightning arrester placed near the generators. Potential furnished by two generators in series, rated 500 kw., 1,500 volts, each machine under-excited. Resistance in series, 20 ohms. Maximum current, 60 amperes; total time of discharge, 16 milli-sec.

The voltage wave shows a drop from 1,790 volts to 210 volts at the first instant of discharge. This large drop is accounted for by the large reactance in the generators. This same reactance of the generator causes a rise in potential over the normal potential of the circuit when the arc has been extinguished in the arrester.

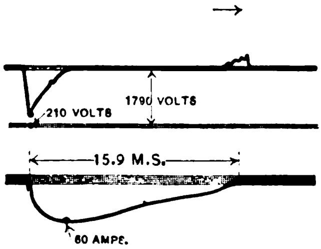

FIG. 26.

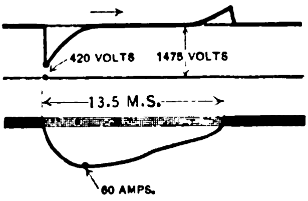

FIG. 27.

Oscillogram Fig. 27. Discharge of lightning arrester on 1,475 volts, direct current. Lightning arrester placed near the generator. Potential furnished by two generators in series, rated at 500 kw., 1,500 volts, each machine under-excited. Resistance in series, 15 ohms. Maximum current, 60 amperes; total time of discharge, 13½ milli-sec.

Again in the voltage wave is shown the rise of potential at the end of the discharge due to the inductance of the generator.

Oscillogram Fig. 28. Discharge of single arrester on 575 volts, at one mile (1.6 km.) from the source of power. Potential furnished from the city trolley. Resistance in series, 22 ohms.

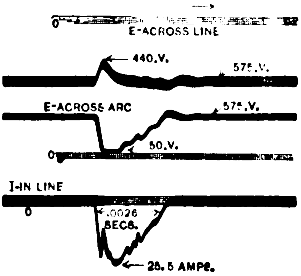

FIG. 28.

In this record not only the current in the arrester and the potential across the line is given, but also the potential across the arc in the arrester. By arrangement of the oscillograph the potential vibrators deflected in the opposite directions.

The potential across the arc drops to 50 volts at the first instant of discharge, and the potential across the line drops to 440 volts. Both potentials recover their original values in a somewhat irregular manner.

The irregularity in the potential is due to the variations in the current, which in turn is due to the condition of the arc chute. The total duration of the arc is 2.6 milli-sec.

It will be noticed in the middle record that the voltage across the arc sticks at 50 volts for a considerable fraction of the whole duration of the arc. This is due to the fact that the current is reduced to a value so low that the force from the magnet is not sufficient to drag the arc out of the gap quickly. In each of the following oscillogram figures, the resistance is successively lowered.

Oscillogram Fig. 29. Discharge of single arrester on 580 volts at one mile (1.6 km.) from the source of power. Potential furnished from the city trolley. Resistance in series, 10 ohms.

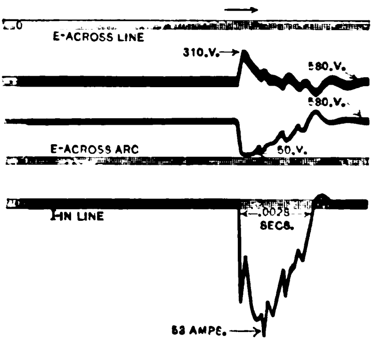

FIG. 29.

In this record not only the current in the arrester and the potential across the line is given, but also the potential across the arc in the arrester. By arrangement of the oscillograph the potential vibrators deflected in opposite directions. The potential across the arc drops to 50 volts at the first instant of the discharge, and the potential across the line drops to 220 volts. Both potentials recover their original values in a somewhat irregular manner.

The irregularity in the potential is due to the variations in the current, which in turn are due to the condition of the arc chute. The total duration of the arc is 2.5 milli-sec. The slight reversal of the current as it is extinguished is due to the presence of an aluminum cell which was used to protect other apparatus on the same line.

Oscillogram Fig. 30. The conditions of this oscillogram are similar in every way to those of the previous oscillogram except that the resistance was reduced to five ohms. Variations in the current potential are somewhat more marked.

Oscillogram Fig. 31. The conditions for this oscillogram are the same as the previous one except that no series resistance was used. In this case the arrester was depended upon to draw out the arc more rapidly than the current rose in the circuit in order to limit the value of current in the arrester to less than short-circuit value.

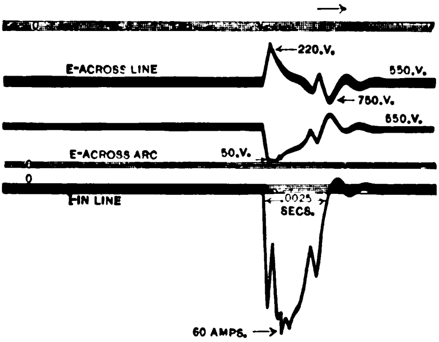

FIG. 30.

The current and potential waves are very much smoothed out due to a better condition of the arc chute. The current rose to a maximum of 184 amperes with a duration of 4.3 milli-sec. It has been pointed out before that the initial rise and drop

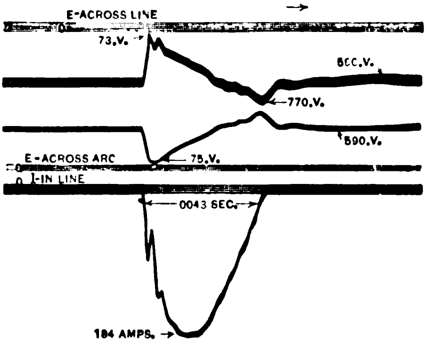

FIG. 31.

in the current which is characteristic of the discharge at some distance from the power house is probably due to the capacity effect of the line.

In the foregoing selected tests the endeavor has been to show how the elements of design of a lightning arrester are

The potential across the arc drops to 50 volts at the first instant of discharge, and the potential across the line drops to 440 volts. Both potentials recover their original values in a somewhat irregular manner.

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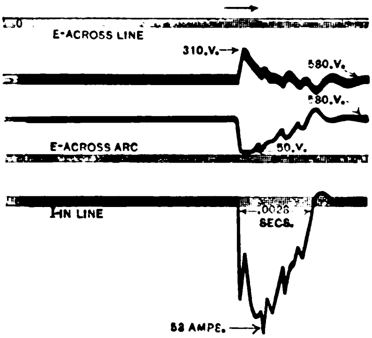
Oscillogram Fig. 29. Discharge of single arrester on 580 volts at one mile (1.6 km.) from the source of power. Potential furnished from the city trolley. Resistance in series, 10 ohms.

In this record not only the current in the arrester and the potential across the line is given, but also the potential across the arc in the arrester. By arrangement of the oscillograph the potential vibrators deflected in opposite directions. The potential across the arc drops to 50 volts at the first instant of the discharge, and the potential across the line drops to 220 volts. Both potentials recover their original values in a somewhat irregular manner.



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The irregularity in the potential is due to the variations in the current, which in turn are due to the condition of the arc chute. The total duration of the arc is 2.5 milli-sec. The slight reversal of the current as it is extinguished is due to the presence of an aluminum cell which was used to protect other apparatus on the same line.

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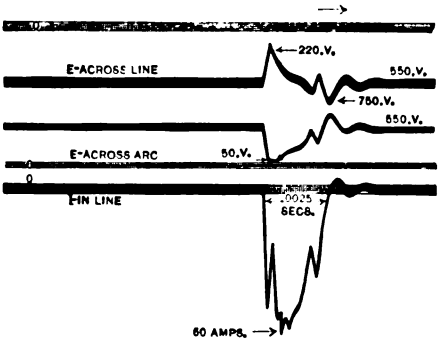

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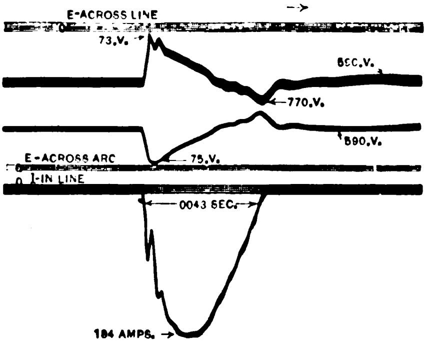

FIG. 31.

in the current which is characteristic of the discharge at some distance from the power house is probably due to the capacity effect of the line.

In the foregoing selected tests the endeavor has been to show how the elements of design of a lightning arrester are predetermined and the methods used for doing it. No attempt has been made to show the tests and methods for determining all the detailed relations of the different parts and dimensions of arc chute, dimensions and spacing of arc grid, strength of magnetic field, distribution of magnetic field, total energy dissipated in the series resistance, total permissible energy in the resistance, quantity of electricity, time of discharge, etc., but it is hoped that sufficient experiments have been shown to demonstrate that the design of the lightning arrester can be made with as great an accuracy as any other commercial electrical apparatus. It is possible to state what an arrester will do under various conditions of discharge imposed upon it, and what degree of protection it will give under each condition. In other words it is possible to state the limitations of each arrester, when it will fail to protect, and when it will fail to extinguish the dynamic arc and be self-destroyed. Each arrester requires a specific rise of potential before it will spark and after the spark it will allow a definite value of current to flow without raising the potential to a dangerous value. This value of current is determined by Ohm's law. For example: If an arrester has 20 ohms in series, then at 1,200 volts, which is double the usual trolley potential, the discharge current will be 60 amperes. If the gap sparks over at 1,200 volts and the lightning discharge is relieved by a discharge of 60 amperes then no damage should result. If, on the other hand, the resistance in the lightning arrester is 2,400 ohms, then in spite of the fact that the gap sparks over on 1,200 volts the arrester cannot discharge at a greater rate than ½ ampere, and it is, therefore, limited to discharges which will be relieved by a discharge rate of ½ ampere.

It will be seen from this discussion that an arrester can be designed to safely discharge lightning strokes of any desired intensity, and that it is entirely a question of compromise between the cost of the arrester, on one side, and the percentage of lightning discharges that the arrester will take care of, on the other side. Under the best conditions attainable in this type of arrester it cannot be made to give as perfect protection as the aluminum cell arrester. On the other hand its up-keep is less at the present time.

A paper to be presented at the Schenectady Meeting of the American Institute of Electrical Engineers, Schenectady, N. Y., May 17, 1912.

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SOME MECHANICAL CONSIDERATION OF TRANSMISSION SYSTEMS

BY T. A. WORCESTER

In any transmission system each of its elements, the supporting structures, the insulators and conductors, has a vital mechanical function and on each may rest the success or the failure of the system. In the early days of high voltage transmission these points were not given due consideration and there were many cases of the destruction of lines due to washouts, sleet and wind storms and frequent breakages of wires due simply to contraction at low temperatures. During later years, however, engineers have profited by these experiences and a greater study has been made of the details of mechanical construction, resulting almost entirely in the elimination of disasters except in cases of most unusual and severe conditions.

The purpose of this is to review in a general way the stresses which must be considered in the various elements of a transmission system and to point out some of the means which have been resorted to to meet certain special conditions. Consideration will be given chiefly to steel tower structures since they are by far the most important type of support for higher voltages. The wooden, steel and concrete poles have their field in the lower voltage range where they are able to compete against the built-up structure.

STRESSES

The stresses which a tower must be designed to withstand are (*a*) those acting in a vertical direction, due to the dead weight of the conductors and insulators, plus an allowance for ice covering; (*b*) in a horizontal direction at right angles to the line, due to wind pressure; (*c*) in a horizontal direction parallel to the line, due to wire breakages. All of these loads are applied at the ends of the cross-arms except a portion of (*b*) which is distributed over the entire tower.

The vertical load depends on the size, material and number of the conductors and ground wires, length of span and thickness of ice coating; the horizontal load at right angles to the line depends on these same elements which determine the exposed surface, and the wind velocity; the horizontal load in the direction of the line depends on the size and number of conductors, the amount of ice and the number of wires which may break at any one time. Each of these governing factors will be briefly discussed.

The size of conductor depends on electrical considerations, except where the length of span is the governing feature.

The length of span, except in river or gorge crossings, is dependent upon the designer and must be chosen so as to give the line the least cost. As the span increases, the number of towers and insulators per mile decrease, but on the other hand the height of the towers must be increased to care for the greater sag and at the same time they must be made proportionately stronger and heavier to care for the greater loads per span. The effect of these changes on the cost of a line is shown by the curve, Fig. 1. The length of a span affects the loads in the vertical direction and in the horizontal direction across the line and not that parallel to the line, since the latter is governed by the size of the conductor, it being necessary to adjust the sag so as not to exceed the safe stress for the wires.

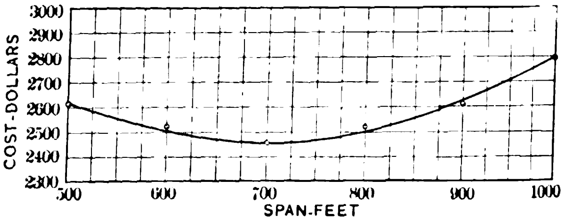


FIG. 1.—COST PER MILE OF TOWERS AND INSULATORS ERECTED.

For every size of conductor there is a practical limit of the length of span beyond which the sags and height of tower becomes excessive and there is danger of the wires swinging together. For the smaller sizes of conductor this limit is quite low (300 ft. (91 m.) for No. 4 cable) and in many cases it will be found more economical to increase the size of conductor so as to permit using a greater span. The following tabulation illustrates this:

	Size of Conductor	Span feet	Sag feet	No. of towers per mile	Cost of towers and insulators per mile erected	Cost of wire and freight per mile	Total per mile
Case I.	No. 4 B.&S.	300	10.5	17.6	$3080	$322	$3402
Case II.	No. 2 B.&S.	360	10.5	14.7	2570	514	3084
					Saving per	mile............	$318

These figures are based on the assumption that the same towers and sags would be used in both cases, giving the same clearance to ground. The sag in Case I is the minimum sag at which wires may be strung on the basis of 0 deg. fahr., 8 lb. (3.6 kg.) wind, and ½ in. (1.27 cm.) sleet and with these same conditions and sag the span for No. 2 wire is calculated and found to be 360 ft. (109 m.). With this tower spacing and No. 2 cable the cost of the line is $318 less than with No. 4 cable and 300 ft. (91 m.) span. It is allowable to assume that the same towers can be used in the second case as in the first since the lightest tower which it is practicable to build would be sufficiently strong for the second case. However, it would be possible to put $20.00 more into the cost of each tower and still have the cost of the second line a trifle less than that of the first and the gain would accrue from the electrical advantages of the larger size of conductor.

A span of 360 ft. (109 m.) is not necessarily the most economical span for the No. 2 conductor. Further calculation indicates that a 500-ft. (152 m.) span could be used with only a very slight increase in the cost of the towers. This limit cannot be extended beyond 500-ft. (152 m.) even though the line with greater spans would have a less cost. Here again the limit depends on mechanical considerations rather than on costs and is governed by the danger of lashing together of the wires in gusty winds.

In long spans over rivers, etc., the standard main line towers and conductors are frequently used. This practise may be permissible in some instances where the spans are not very much greater than normal but when the towers have been designed to closely meet the demands of the standard spacing it becomes dangerous to use them for any appreciably longer spans. It is advisable in these instances to use dead end anchor towers with strain insulators and thus isolate the crossing span and prevent any trouble in other parts of the line from being carried into it.

For very long spans it is, of course, necessary to use conductors of greater mechanical strength than are used in the main part of the line and the supporting structures must likewise be made correspondingly stronger. Too great care cannot be taken in planning such structures as unusual stresses are likely to occur and would result seriously unless properly cared for. More than average allowances should be made for wind, sleet and temperature and a greater factor of safety should be used in the design of the steel work.

Ice and Wind

The amount of ice which may form on wires has been a much-discussed topic and one which will probably never be settled to the satisfaction of all concerned. However, the various engineering bodies have about agreed that it is safe to consider ½ in. (1.27 cm.) ice in conjunction with 8 lb. (3.6 kg.) wind pressure and 0 deg. fahr. as the worst combination of conditions likely to occur in the United States. It is conceded that there have been thicker formations of ice and greater wind pressures, yet the probability that they will occur simultaneously and with low temperature is so remote as to make it seem unnecessary to consider them. There is little doubt, however, that those engineers who have experienced destruction of their lines by sleet and wind storms will never use anything but the most conservative allowances. For spans crossing rivers, highways or railroads more liberal allowances are always made, the standard being ¾ in. (2 cm.) ice, 11 lb. (5 kg.) wind and 0 deg. fahr.

Ice and wind on the cables work together to increase all of the loads on a tower structure; the vertical load and the horizontal load in the direction of the line, by giving increased weight to the conductor, and the horizontal crosswise load by giving greater surface for the wind to act upon.

Wind on Towers

There is a great difference of opinion as to just how much wind pressure shall be allowed on the tower itself. It is certainly not sufficient to base this allowance on the same assumptions as are used for the conductors. Those assumptions are for wind velocities likely to occur simultaneously with heavy loading of ice and low temperature. Greater velocities may occur independent of these last factors. It is, therefore, advisable to allow for at least the highest recorded value. This value, as indicated by the Government anemometer is very nearly 100 mi. per hr., which corresponds to an actual velocity of 76.2 mi. per hr. and a pressure of 23.2 lb. (1005 kg.) per sq. ft. (=0.09 sq. m.) ($0.004 \times V^2$ for flat surface). The government anemometer records the velocities only at intervals and does not give all instantaneous values and these instantaneous values may be somewhat greater than those at the moment the record is taken, due to the gusty character of winds. It has been estimated that these gusts cause velocities 50 per cent greater than those which are recorded. Another feature enters, however, to somewhat counterbalance this effect, viz., the height above the earth surface. The anemometer records are taken well above the earth surface, while transmission structures are seldom higher than 75 ft. In consideration of these variables and uncertainties it is not possible to give one value of pressure to be used on all lines. A safe range of pressure though would be from 20 to 35 lb. (9 to 16 kg.) per sq. ft. (=0.09 sq. m.) depending on the general character of the country which the line traverses, *i.e.*, whether it is exposed to sweeping winds or protected.

It will usually be found that the maximum wind pressure acting on the bare towers and wires will have a greater overturning moment than that caused by the maximum wind assumed to accompany ice formation, acting on the ice-coated wires and towers, *i.e.*, the greater pressure due to the higher velocity of the wind, even though exerted on a smaller surface, will overbalance the less pressure acting on the greater surface. For this reason the side pressure on towers should be figured for both conditions and the design should be based on the loads caused by the worst of the two.

In calculating the wind on the towers the entire projected area of two lateral faces should be used as the surface over which the wind acts.

Wire Breakages

The most serious stresses which a transmission tower is called upon to withstand are those due to the breaking of conductors. Lines are put up with a view of not having the conductors break but there are certain unavoidable conditions which frequently produce breaks. The most usual of these are (*a*) burning of the conductors due to short circuits or grounds started by lightning, large birds, swinging together of wires, etc., or through malicious intent; (*b*) breaking of conductors due to crystallization or fatigue of the metal produced by kinking during erection or by insufficiently rounded edges of cable clamps and (*c*) by overloading of conductors during extreme conditions of temperature, wind, etc.

The causes in (*a*) have been overcome to a great extent by the use of various devices, principally the arcing ground suppressor, the ground ring and metal sleeve. The swinging together of conductors occurs only when light conductors are used in too long a span where they will be likely to lash in the wind. Ordinarily in well designed spans the wires swing in unison so that there is no danger of their coming together.

The breaking of wires due to kinking is frequently not given due consideration and many lines erected by careless workmen have suffered from this cause. The elasticity and strength of the metal on the inside of the bend is decreased enormously by a short bend and when the wire is straightened out and drawn taught by frequent strains in the line it will finally weaken to the point of rupture. Likewise, many breaks have been caused by repeated bending of the conductor at the wire clamp on the pin type of insulator. The localization of the stress by a hard metal clamp finally makes the metal of the conductor brittle and rupture occurs well below the average tensile strength. A clamp may have well rounded edges and still cause trouble. It is the rigidity of the clamp as well as too sharp an edge which is harmful.

When all of the wires of a transmission line are intact there is no pull on the towers in the direction of the line (*i. e.*, on the intermediate towers, not the dead end or other special structures). As soon, however, as a conductor is broken the strain which it took to cause the break is thrown on the adjacent towers. Obviously, therefore, the maximum load which the cross arm must stand in the direction of the line is equal to the tensile strength of the conductor which is used. For the smaller sizes of conductor this rule is usually observed but for the larger sizes less liberal allowances are usually made. It is customary with the larger sized conductors to allow for a stress equal to one-half of the ultimate strength of the cables. This value is chosen since it is the maximum safe working stress, above which the cables are likely to stretch permanently.

With the suspension type of insulator the full length of an insulator string is thrown into the line when a break occurs and the strain in the conductor and on the cross arm is greatly reduced. But little consideration should be given to this fact, however, since there is a severe jerk when the insulator is drawn to its new position and the effect on the tower is not less and may be more than occurs when the pin type of insulator is used.

A question which naturally arises is how many conductors may break at any one time. This depends to a large extent on the cause of the breaks. If due to lightning or large birds it is probable that not more than one or possibly two conductors would break; but if due to poorly designed wire clamps, injury of wire during erection, or to excessive sleet and wind, it is conceivable that all might break. It is very rare, however, for all of the conductors to break, and further, it is hardly practicable to make such an assumption when considering main line towers since it would raise the cost of the line to a prohibitive value. It is usual to compromise by allowing for the breakage of only two cables of a three or six conductor line and to safeguard the system by interposing anchor towers at frequent intervals. These anchor towers would be capable of withstanding the strains due to the breakage of all of the cables and would thus divide the line into isolated sections so that any trouble in one could not be communicated to the other.

In the rigid type of tower practically all of the stress caused by the breaking of several conductors is cared for by the tower itself, *i. e.*, the movement of the top of the tower is not sufficient to permit an even distribution of stress between the unbroken cables of the damaged span and those in the adjacent spans. With the flexible type of tower, however, the effect is different. The tower is designed to be rigid in the plane across the line and flexible in the direction parallel to the line so that it will bend and allow an even distribution of stresses in the adjacent spans. For instance, consider a three-conductor system with one ground wire and assume that each cable has an ultimate strength of 6,000 lb. (2,721 kg.) and is strung to have a tension of one-half of its ultimate strength under the worst conditions likely to occur, and assume that these conditions prevail. Suppose that one of the conductors has been injured or is defective and that it breaks under this load. The tops of the towers on either side of the break will be pulled over by the four cables in the next span until the total tension in them would be just balanced by that in the remaining conductors of the damaged span.

This tension would amount to very nearly 12,000 lb. (5,443 kg.), *i. e.*, 4,000 lb. (1,814 kg.) per cable or 33 per cent more than the allowable stress. This load would not break the cables but it would stretch them beyond the elastic limit and permanently weaken them.

Suppose that two cables had broken instead of one. Each of the remaining two would be strained with nearly 6,000 lb. (2721 kg.), an amount almost equal to its ultimate breaking strength. The stress would not be quite 6,000 lb. because the tension in the adjacent spans would decrease rapidly as the cables in the damaged span are stretched to greater length. However, the example serves to illustrate that it is necessary to use very much greater factors of safety in stringing conductors in a flexible tower system than would be used in a rigid system.

FOUNDATIONS

The foundations of a tower are of prime importance, yet under average normal conditions they offer but a small problem. In ordinary straight line work, over fairly level country, where the soil is hard or rocky and where the smaller sized conductors are used no special foundations are necessary; the ground stub with cross piece or foot may simply be buried in the ground with a little rock filler and if the spread of the tower legs is normal there is little to fear from tilting. With the larger sizes of conductor and longer spans the overturning moment frequently reaches such proportions as to make it advisable to use concrete foundations and thereby eliminate the need of spreading the tower legs an excessive amount. When towers must be placed where the soil is loose or marshy or where they may be endangered by floods or landslides it is essential that special consideration be given to the design of their foundations. It may be necessary to resort to any one of several types of construction; steel or timber piling, crib work, rock filling or concrete, or a combination of two or more of these. Fig. 4 shows one of the best types of foundation, used to meet a very special condition where it was necessary in order to gain entrance to a city to extend the right of way along the lake front and place the tower footings in the water.

Angle, hillside and anchor on long spans present serious problems from the foundation standpoint and must be carefully and liberally designed so as to allow no motion or slip whatever. It frequently pays to make a long detour in order to avoid bad hillsides or crumbly crests.

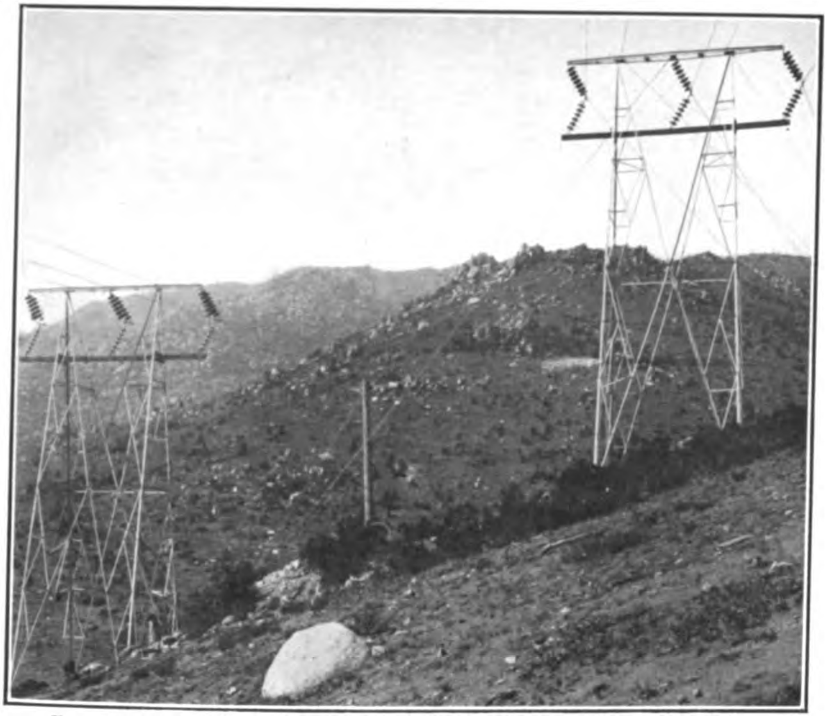


FIG. 2.—DIFFICULT ANGLE AND HILLSIDE CONSTRUCTION. [WORCESTER]
Great Falls Water Power and Townsite Company.

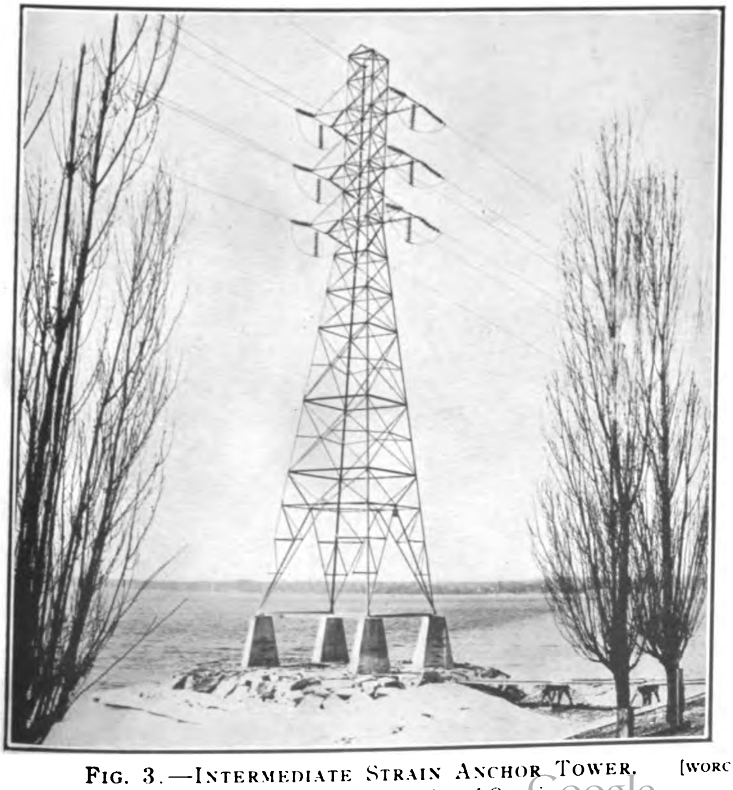
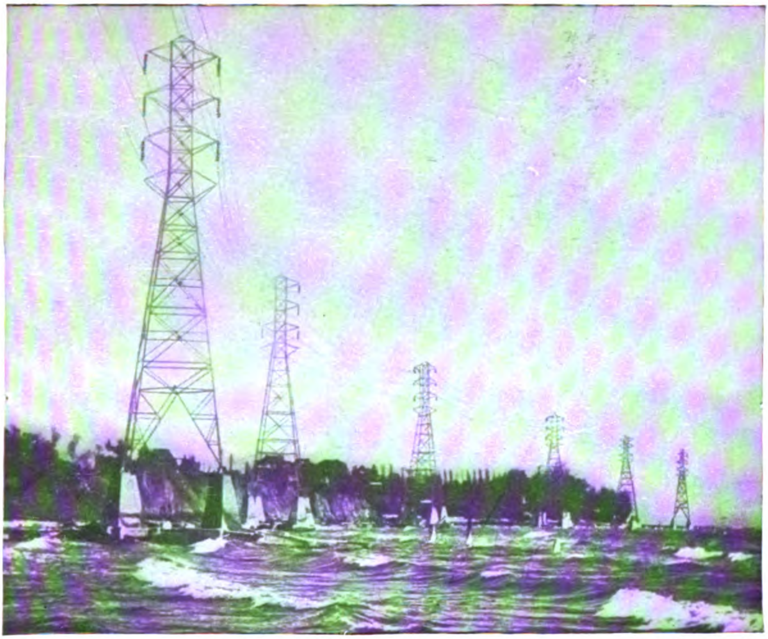
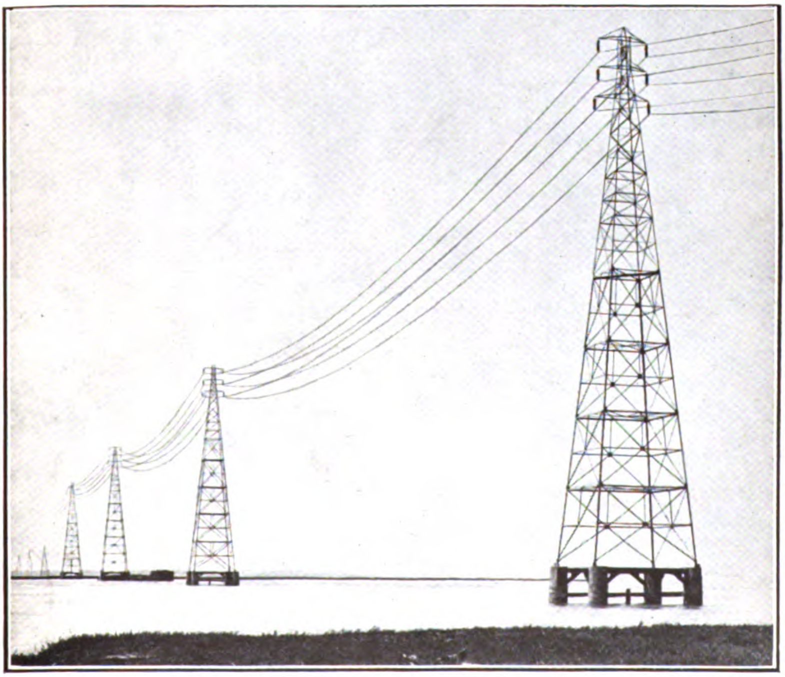


FIG. 3.—INTERMEDIATE STRAIN ANCHOR TOWER. [WORCESTER]
Hydro-Electric Power Commission of Ontario.



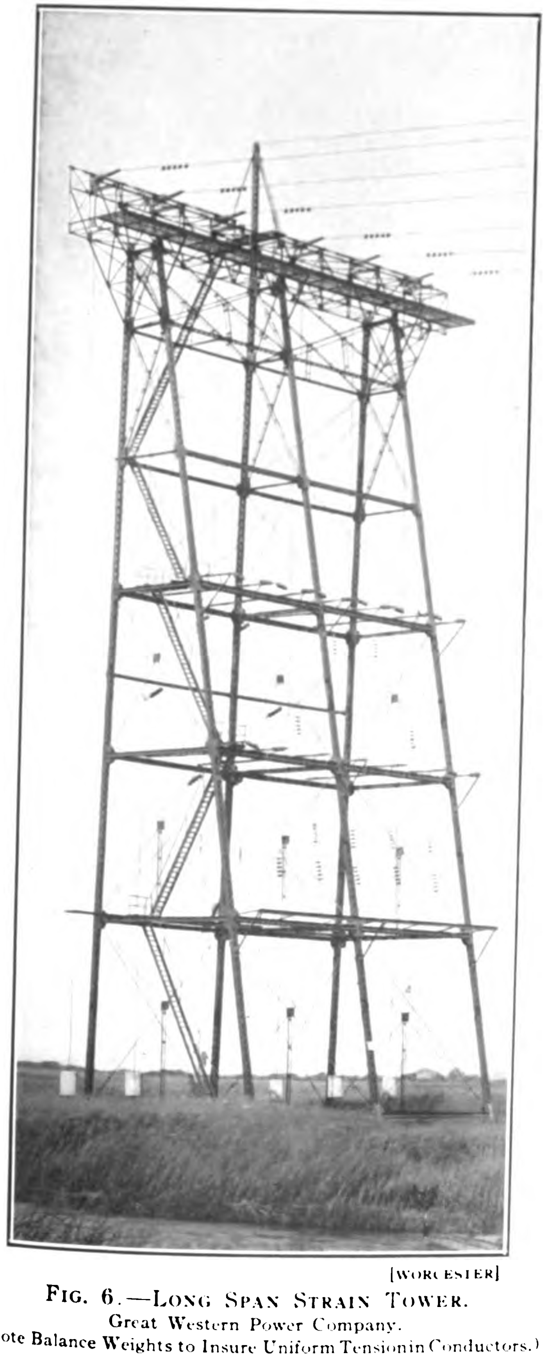
[WORCESTER]

FIG. 4.—TRANSMISSION LINE ENTERING TORONTO.
Hydro-Electric Power Commission of Ontario.



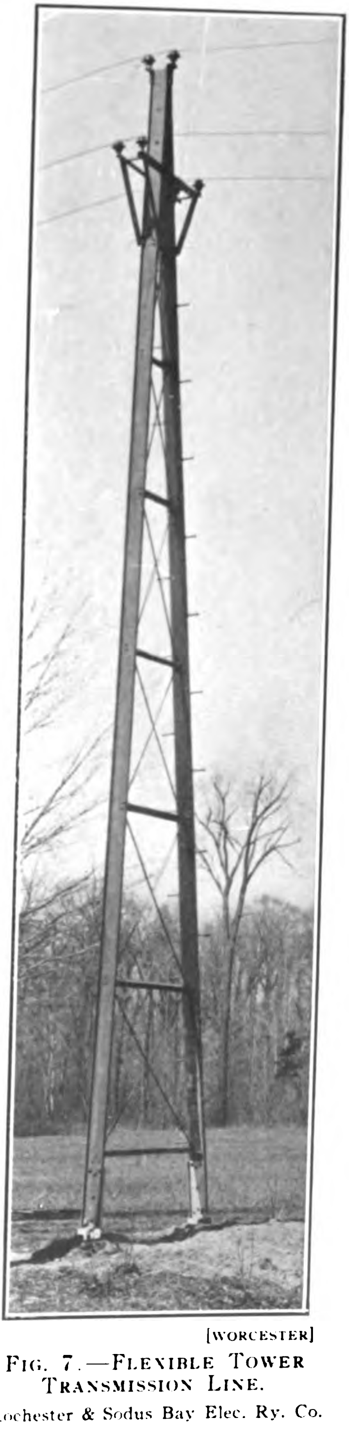
[WORCESTER]

FIG. 5.—STANDARD 50-FOOT TOWERS ON 87-FOOT LOWER EXTENSION—SPANS, 750 FEET.
Sierra and San Francisco Power Company's Line Crossing San Francisco Bay.



[WORCESTER]

FIG. 6.—LONG SPAN STRAIN TOWER.
Great Western Power Company.
(Note Balance Weights to Insure Uniform Tension in Conductors.)



[WORCESTER]

FIG. 7.—FLEXIBLE TOWER TRANSMISSION LINE.
Rochester & Sodus Bay Elec. Ry. Co.

It must be remembered that a very slight tilt at the base of the tower means large displacement at the top which may exert considerable extra tension in the conductors and in the case of the suspension insulator may bring the conductors dangerously near the tower.

FACTORS OF SAFETY

In the design of all mechanical structures it is customary after assuming certain conditions of loading to allow a factor of safety; in other words, to design the parts so that their ultimate strength will be several times their assumed loading. The amount of this factor of safety depends on (*a*) the character of the load—whether steady, intermittent, or otherwise—(*b*) on the knowledge one has relative to the amount of load; (*c*) on the ease or difficulty of calculating the structure to care for the assumed loadings; (*d*) on the possibility of faults in construction and (*e*) on the risk to life and property. In a transmission structure the load is intermittent and reversing and our knowledge as to its amount is not definite. These features tend to demand a relatively large factor of safety. However, this tendency is more than counterbalanced by the facts that it is not difficult to calculate the stresses when a definite load is assumed, that the chance for faults in manufacture are but few and that the risk to life and property is a minimum.*

Another feature which makes it possible to use a small factor of safety is that a sample tower may easily be tested with the assumed loadings and with ultimate breaking loads. Obviously if a factor of safety is used which will permit the tower to be strained with the assumed loads without being permanently deformed then such factor of safety will be satisfactory, provided the assumed loads correspond with the actual loads. The factor of safety for these conditions would be two if it is considered that the elastic limit of the metal is one-half of its ultimate strength. Many transmission towers have been built on this basis with a consequent saving in the cost of the line. On the other hand more conservative engineers have used values of three and even four, these higher values being chosen to care for the uncertainty of load conditions. In one line recently built a factor of safety of 4 was used for all of the main line towers and three for all the strain or dead end structures. This at first sight seems illogical, but it is justified, since the strain towers are figured for a very definite condition; *i. e.*, of all cables being broken in one span and with a maximum load of wind and ice on all those in the next span; whereas the intermediate towers are figured on an indefinite assumption; *i. e.*, of having only two cables break while the others are heavily loaded. The use of these large values, however, makes the cost of the line excessive and for this reason it is common practise to use smaller values, two, two and one-half, or three for the intermediate towers and three or three and one-half for the strain towers. With this arrangement the main part of the line will be safe except in case of some unusual condition which produces worse loads than those assumed and in event of such an accident the strain towers will prevent the trouble from traveling to the next section of the line.

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*Except at railroad and highway crossings, etc.

For the conductors themselves a factor of safety of two is sufficient except for very long spans and crossings, in which cases slightly larger values should be used unless a greater allowance is made for ice and wind than in other parts of the line. Larger factors of safety also must be used in conductors in flexible tower systems, as pointed out under "Wire Breakages."

FLEXIBLE TOWERS

The flexible tower was discussed above with special reference to the stresses induced in the unbroken cables when one or two cables should break in one span and it was found necessary to string the cables with less tension than in a rigid tower system. When this is done the flexible system immediately becomes mechanically stable and is of value. Economy is secured by the small weight and cost of the towers without unduly sacrificing the safety of the system.

A special field for the flexible tower appears to be for the higher voltage systems in which a double tower line of three conductors each is desired. There are a number of advantages in using such a system in preference to the six-conductor single tower system, the principal ones being that there is less liability to complete shut-down in case of accident to a tower and that there is greater safety for linemen when repairing damaged towers, conductors or insulators. The reason for the present limited use of double tower lines is the high cost of such a system when made up of the rigid type of tower. If engineers would look more into the possibilities and cost of the flexible structures there would undoubtedly be a more general use of double tower lines.

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SOME IMPRESSIONS OF THE ELECTRIC TRACTION SITUATION IN EUROPE

BY C. E. EVELETH

No attempt will be made to go into descriptive accounts of the various installations as these have already been well covered by articles in the technical press. At the present time there is evidence of considerable activity in making plans for rather extensive electrifications for steam railroads in the various European countries. In different sections of the continent the conditions bringing about electrification are varied, the more prominent perhaps being the greater capacity obtained for tunnels where the traffic is now limited by problems of ventilation, the utilization of cheaper grades of fuel for the generation of power, the attractiveness of utilizing water powers which may be developed at low cost, the elimination of expensive steam pusher service on mountain grades, and the electrification of steam tracks where the limit of the quantity of transportation which can be supplied under steam-operated conditions has been reached.

It may help to understand the difference in viewpoint between European and American engineers by calling attention to a few fundamental differences between the European and American transportation requirements. Perhaps the most fundamental difference is in the relative magnitude or the drawbar pulls required for handling either freight or passenger trains. The ordinary European drawbars are designed for normal working pulls of 12 to 15 tons, and breaking strengths of approximately twice these values. With American drawbars some recent tests have shown that their breaking strength is from 100 to 150 tons, and the normal working values may be considered about 40 or

50 tons. In other words, the American drawbars will stand at least three times as much as those in use on the continent. Over there they have practically no automatic couplers, the cars being generally coupled together by links with turnbuckles. The train weights in Europe are generally about one-third of those in this country, and practically never exceed half the weights of our ordinary trains. These limitations are such that with a liberally powered locomotive not more than 60 tons can be utilized on the drivers in Europe, whereas we do not hesitate here to couple two locomotives together, giving a total weight on the driving axles at the head end of the train of about 200 tons, as in the Detroit River and the Great Northern Railway electrifications. In Europe it is customary to design locomotives with plate frame structures to withstand end strains of about 30 tons. In this country it is customary on account of the automatic coupling and shocks while in shunting service to design the locomotives for an end pressure of approximately two and one-half times the locomotive weight, or 250 tons for a 100-ton engine.

This naturally leads to radically different types of mechanical design and the lower tractive effort at starting demanded for the European machines results in equally radical differences in the electrical design of the motors, since materially greater drawbar pulls are required from the American engines.

In general the schedule speeds for suburban passenger service are much lower than in this country. This is particularly true of Germany. There are, however, individual and notable exceptions to this condition.

Bearing in mind these differences in requirements, it may be of interest to review briefly the impressions obtained in the different countries. These impressions come from a visit to the various railroads referred to and discussion of the problems with the engineers interested.

ENGLAND

For the present the electrification problem in England seems to be essentially one of heavy city-suburban traffic. Several of the large cities, notably London, Manchester and Liverpool, are confronted with problems of this character. The operation of the present electrical suburban systems in England has been successful in increasing traffic receipts, and the various elements which go to make up the installation costs, operating costs, etc., are beginning to be better understood. The directing heads of a number of the principal railroads seem to be satisfied that electrification is coming and are inclined to face the problem with considerable aggressiveness.

With the exception of the electrification of the London, Brighton and South Coast Railway, very little new work has been done in England during the last five or six years. At the present time, however, considerable activity is evident and a number of English railroads are making studies of extensive electrifications with the idea of very soon putting them into effect.

Suburban electrification in large cities has been very much affected by the introduction of motor buses and the extension of surface tramways. This, together with the advantage from electrification, is well illustrated by the experience of the London, Brighton and South Coast Railway on its loop from London Bridge to Victoria station, where the conditions appear to have been approximately as follows:

About seven or eight years ago on this division, when operated by steam, there were sold in the neighborhood of eight million tickets per year. On account of the competitive surface transportation development, the sales dropped to about three and one-half million tickets per year. Electrification was completed on this division about two years ago, and since that time the ticket sales have increased until now they are at the rate of approximately nine million per year. This result is brought about by the more frequent and better train service made possible with electrification, and the results have been so convincing that the directors of this road are particularly receptive to electrification possibilities and are already talking of making considerable extensions to their system.

In England there seems to be some difference of opinion regarding the relative merits of the direct-current and single-phase system, though a general consensus of the engineering public opinion at this time seems to indicate a decided preference for direct current for the English conditions, and practically all of the new electrification projects will be carried out with direct current. There is, of course, an exception in the case of the London, Brighton and South Coast line, which will undoubtedly carry out the extensions with its present single-phase system. Experience of both the London, Brighton and the Midland engineers with the single-phase system has been somewhat disappointing in that the installation costs have considerably exceeded the estimated costs. There seems to be no question but that the present electrifications could have been carried out more cheaply with the 600-volt direct current. No operating costs have been made public on the Brighton system. This is natural, since the manufacturers of the equipment appear to be still interested in experimental development in connection with the motors and control, so that all maintenance is not yet entirely in the hands of the railway company.

There seems to be considerable interest awakening in England in the question of using direct-current voltages higher than 600, and a number of the electrifications under consideration are being studied on the basis of 1,200 volts and higher. One manufacturer has already built and had in operation for a year a 3,500-volt direct-current locomotive, which is said to have given excellent satisfaction. It is rather interesting that the power for this locomotive is furnished by a 3,500-volt generator having one commutator.

There are several things which have held back electrification in England. Due to the light rolling stock and low operating costs, particularly in the elements involving rolling stock and power, the possible savings due to electrification are perhaps rather less than would ordinarily be encountered in America. There is also difficulty in raising capital for such projects, since the present capitalization of British railroads is very much higher than in this country, and the directors of the roads are extremely reluctant to add anything to their present burden of fixed charges.

HOLLAND

Transportation in Holland is unique on account of the extensive system of canals. There is very little internal distribution of freight by the railroads. The greater part of the earnings must therefore be obtained from passenger service and the greatest economy is required to bring a reasonable return on invested railway capital. It is, therefore, hardly likely that any considerable electrification of steam railroads will take place in Holland, as there are comparatively few sections where the traffic conditions warrant it.

The single-phase electrification between Rotterdam and Scheveningen has been taken over by the paralleling steam railroad. The cars on this line are, from the standpoint of comfort, perhaps the best electric cars in Europe. The schedules are not severe, as the service calls for an average of about one stop in ten miles. The maintenance costs on this railroad are rather high and no extensions on this system are at present contemplated.

FRANCE

The French people have always been famous for their scientific experiments, and this national characteristic is well illustrated by the present installations for electric transportation. It is rather interesting to note, for instance, that a single railroad company in Paris is operating over its tracks cars propelled by a considerable number of different systems of motive power, among them being the electric surface-contact system, overhead trolley, underground conduit, storage battery cars, steam cars with flash boilers, steam cars with boiler storage and cars operated with compressed air on which the air is superheated before being used in the air motors.

The engineers of the Paris-Mediterranean Railway have developed a locomotive taking power from a single trolley and operating direct-current motors on the axles, the current for these motors being transformed by means of a very ingeniously designed synchronous commutator known as the "permutator." In its present state this locomotive is rather expensive and is not in commercial operation, the work up to the present time being of an experimental character.

The single-phase system is represented in France by one or two small tramway lines and undertakings being carried out by the Midi Railway Company. This company has purchased five different single-phase locomotives from as many different manufacturers for operation on the experimental lines in the south of France. The conditions on this electrification are peculiar in that sections of the line involve heavy grade haulage and regenerative braking has been specified. Up to March, 1912, three locomotives had been delivered. The electrification of this section of the Midi Railway is being carried out under certain government subsidies, without which electrification would hardly be justified, as there is little traffic on the lines under consideration and but a few trains per day. Up to the present time everything has been experimental and no operating data are available. Several of the lines to be electrified have not yet been built, and it will probably be several years before the locomotives are in active commercial operation.

The 2,400-volt three-wire direct-current system at Mure is now being extended with a trolley having 2,400 volts between the contact conductor and the track. The 60-h.p. motors for the passenger cars of this extension, when operating at 50 per cent. over potential, at 100 per cent. overload in current, looked very good on the test stand, and they will undoubtedly be successful in operation.

Without question the most serious undertakings contemplated in France today are those connected with the electrification of the steam roads at Paris. Both the State Railways and the Paris-Orleans Railway contemplate considerable extension of their electric suburban lines. In both instances these electrifications will be carried out with direct current and the third rail. It is the belief of the engineers of the French State Railways, who have made a comprehensive comparative analysis of the various systems available, applied to different traffic conditions, that direct current is the cheapest in first cost and the most economical system to operate for any of their lines upon which electrification is desired.

SWITZERLAND

In this country one naturally turns first to the Simplon tunnel, as it is the only heavy traction system in operation in Europe outside of Italy, and is of special interest on account of the long period of time it has been in operation. This division of the State Railways is equipped with a three-phase system. Its operation seems to be in every way successful and satisfactory. Judging from the appearance of the repair shops and the number of men at Brigue where the locomotives are maintained, the roundhouse costs for these machines must be very low. In this tunnel they have had a condition unusually difficult to successfully cope with in an electrical engine, and their method of overcoming the difficulty is interesting. Great trouble was experienced from insulation breakdowns on both motors and transformers due to condensation when the cool locomotive passed through the center of the tunnel where there are a number of hot springs and the tunnel temperature is about 115 deg. fahr. This condensation resulted in every portion of the electric locomotive being drenched with water. It is now avoided by keeping the locomotives warm by allowing them to stand over pits at the terminals in which heaters have been arranged.

The other three-phase installations in Switzerland, while interesting individually, in most instances are carried out under peculiar local conditions, so that experience on these lines cannot have very general application. Practically all of the Swiss railways involve operation on rather steep and long grades. In addition to the three-phase electrification of light railways, there are a number equipped with single-phase and with 1,200-volt direct current.

The single-phase trunk line installations have been represented by the experimental installation on the Sieback-Wettingen line, which, after operating somewhat over a year, was said to be discontinued on account of high operating costs, due largely to infrequency of service, and on account of the rather serious interference with the national telephone and telegraph systems.

At the Loetschberg tunnel, which will be opened within the next year or two, some experimental work has been carried out and the engineers have decided to adopt single-phase current and have now in operation at Spietz one 100-ton, 15-cycle freight locomotive built by the Oerlikon Company. This machine is at present used to haul one train per day weighing about 300 or 400 tons between Spietz and Fruitigen, a distance of about ten miles (16 km.), the maximum grade being 1.5 per cent. The work on this division up to the present time has been of an experimental character and has not been continued a sufficient length of time or with sufficient severity of service to indicate as yet what results may be expected of this installation. At the present time there are on this division three electrically equipped motor cars. It is understood, however, that future passenger trains will preferably be hauled by electric locomotives. The locomotive selected is a two-motor geared side-rod machine with a single helical gear.

The electrical engineers of the Swiss Government have made comparative studies of the various systems to enable them to select a system for the Gotthard tunnel electrification, which may be carried out within the next two or three years. As a result of their analysis they find that the single-phase system is about 20 per cent less in first cost than the three-phase system and about 33 per cent of the cost of the undertaking if carried out with direct current. This great difference between the installation cost of the direct current and the single-phase is interesting as it is much greater than has ever been found in any analyses of conditions in America. Some of the fundamental assumptions of the Swiss analysis are as follows:

Cost of single-phase and direct-current locomotives essentially the same.

Each substation equipped with motor generator sets and complete installation of spare units in each substation.

Each substation equipped with storage batteries.

Substations located half the calculated required distance apart to insure continuity of service in case of disaster shutting down any individual station.

Voltage regulation conditions have apparently been taken considerably better than are generally adopted in America.

In considering the operating costs, there seem to have been no fundamental cost data available, and it has been estimated that the direct-current and single-phase locomotives will have essentially the same maintenance cost and that this will be in the neighborhood of half that required for the steam locomotives.

ITALY

By far the most important electrifications in Italy are the three-phase installations carried out by the government at Valtel-ina, Mount Cenis and the Giovi tunnel near Genoa. The electric traction applications in Italy have been made on mountain grades and the electrifications contemplated in the immediate future involve similar conditions. The work which has been done has been carried out in a most practical and thorough manner, and has proved both from installation and operating costs entirely satisfactory to the government. The extensions now contemplated involve the purchase of several hundred locomotives within the next few years.

The electric locomotives on the Genoa division will soon, if they do not already, haul about 15,000 freight cars per day. This electrification is a commercial one in every sense and is in fact by far the heaviest section of electric traction on the continent. The results from regenerative braking have been more satisfactory than were anticipated. A most extraordinary and perhaps unexpected saving has been found from the saving in the wear of the track rails. When the Giovi tunnel was operated entirely by steam the up-grade rails lasted about twelve years and the rails on the down-grade tracks about three and one-half years. Apparently the restricted axle movements with brakes on the descending steam train resulted in a scouring action on the rail head. At any time during the steam operation, fresh deposits of metallic dust from the rails and brake shoes were to be seen on the ballast.

Since the inauguration of electric operation under the same traffic conditions about one and one-half years ago, the indications are that the down-grade rails will last as long as those on the up-grade tracks. This saving of practically two sets of rails in twelve years with the tonnage over the Giovi tracks is recognized by the maintenance of way department of the government railroads, and is being allowed as one of the electrification economies in the studies of their divisions where electrification is contemplated and the tonnage conditions correspond to those at Genoa. This saving alone is estimated to be equivalent to approximately the total interest on the power plant and transmission system. So far as I know this character of saving has not been recognized in America, probably due to the fact that practically all of our tunnels with grades are single track and the difference of wear between the ascending and descending tracks has not been recognized with the steam service.

Regeneration has also effected a material saving in coal at the power house with the present electrification. The calculated saving was anticipated to be 16 per cent. By running a period of time utilizing regeneration and a period without, keeping careful track of the tonnage of the load, a saving of 17 per cent of the coal has been realized at the power house. When the entire division is electrified, and this work is now progressing as rapidly as possible, the calculated saving in coal will be much higher. The difference in the energy represented by the present saving and anticipated saving is now wasted in the water rheostats at the power house, which are adjusted to dissipate energy in excess of that which can be utilized by ascending trains.

The Italian engineers are enthusiastic over the three-phase system for their conditions, and such results as have been obtained certainly warrant their enthusiasm.

GERMANY

The progressive and aggressive attitude of the electrical engineers of the German government produces an atmosphere very pleasing to all who are interested in furthering electrification of steam railroads. The most important contemplated developments in Germany are in connection with the state-owned properties. The government engineers believe in the economic advantage of electrification which permits the use of inferior grades of brown coal not suitable for ordinary locomotive service. They are receiving the necessary financial support of the Reichstag. About six years ago the engineers decided upon the standardization of single-phase with the belief that this was best adapted to these conditions, which require uniformity of system chiefly for military reasons. Having reached this decision the relative costs or operating expenses of this system compared with others has not been investigated.

Up to the present time all of the government work has been of an experimental character, but this has been combined with commercial operation in the case of the Hamburg-Blankenese-Ohlsdorf line where multiple unit motor car trains are in use. The locomotives purchased by the government and now in experimental service at Dessau are maintained by the manufacturing companies who furnished them so that they can get the benefit of all the operating experience possible and make such changes and improvements as may seem desirable. These single-phase locomotives at Dessau are if anything rather less powerful than the steam locomotives they are intended to displace. They are built with direct side-rod connection from the motors to the jack shaft, hence to the wheels by connection rods without any interposed springs to take up the vibration from the pulsating torque. Such springs have generally been considered desirable for locomotive work in this country and it will be interesting to see what the outcome of their experience at Dessau will develop. It is further interesting to note that the tendency in Germany seems to be to make a single motor do as much as possible, coupling it to several driving wheels; while in this country the tendency seems to be for a multiplicity of small motors connected in some way to the wheels through gears, thus permitting rather higher armature speeds. The German engineers, while expressing themselves as satisfied with the performance of their single-phase motor cars, are inclined to believe that the future work of electrification will be carried out with locomotives, the operating costs of the Hamburg equipments having proven rather high.

At Hamburg a very interesting comparison between motor-car operation with single-phase and 800-volt direct current will soon be available, as the Hamburg-Hochbahn, occupying for a short distance the same right of way as the Government single-phase line, is equipped with the 800-volt direct-current, third-rail system. The schedule speeds of the two roads are practically the same, though the direct-current system makes an average stop in about 1,900 ft. (579 m.) as contrasted with an average stop in 4,000 ft. (1,219 m.) for the single-phase.

For the electrification of the Stadtbahn-Ringbahn in Berlin where the limitation of strength of the drawbars makes it impossible to obtain the desired acceleration with one single-phase locomotive, it is the intention to use two such locomotives, one at each end of the train. The exact type of these locomotives has not been determined, except that they will each be equipped with a single motor and side rods. Some unique methods of motor and transformer cooling are being proposed, but the final details have not been settled. The program of the German government contemplates the purchase of several hundred locomotives during the next three or four years and the electrification from Magdeburg to Halle; about 145 miles (233 km.) in Silicia have already been authorized. Up to the present time no operating costs from Germany are available as the work has been more or less of an experimental nature and the policy of the government seems to be adverse to the giving out of operating information of this character.

All of the principal German manufacturers of electric railway apparatus are just now taking a very active interest in the development of high-voltage direct-current equipments and have furnished material for a dozen or more railroads at potentials of 1,000-volt direct-current or over.

There are a dozen or more gas-electric cars in passenger service on the Russian frontier, and it is understood that about one hundred more are soon to be built.

SWEDEN

The conditions in Sweden under which electrification is justified on account of the economic returns are rather different from those in any other European countries, with the exception of Norway. There is no coal in Sweden. Water power can be developed at a very low cost and with immense storage capacities which insure continuity of power supply. For these reasons electrification on some lines will undoubtedly be justified where there is a train only once in three or four hours. The Swedish engineers have done a very considerable amount of experimental work, particularly in developing a distribution system which will be of very low cost and sufficiently substantial to be serviceable under their conditions of infrequent service. The electrifications in Sweden are very properly being undertaken with a single-phase current, since, due to the relatively small quantity of rolling stock, the first cost and maintenance costs of the locomotive are relatively unimportant elements of the total operating expenses.

The Swedish Government has recently contracted for the equipment of one of its lines in Lapland to transport iron ore from Kiruna to Rikgransem. There are not at the present time any single-phase electrifications in operation in Sweden, the experimental lines having been dismantled.

The Swedish engineers are further engaged in the development of gasolene-electric and Diesel-electric car equipments in which they seem to have considerable faith, and it is their intention to use these equipments very generally throughout the kingdom.

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ELECTRICAL CHARACTERISTICS OF THE SUSPENSION INSULATOR

BY F. W. PEEK, JR.

On the transmission line proper there are two electrical factors that fix the maximum voltage which may be used. First, the direct loss of energy into the air due to corona, second, arc-over or puncture of the line insulator.

The invention of the suspension insulator a few years ago went a great way toward eliminating the second factor. Transmission voltages were immediately raised to a point over 66,000 volts, where the corona factor began to be apparent practically, and seemed to be the limiting, or was rather, the doubtful one. This lead to very extensive investigations of the laws of corona formation and loss. The effect of corona can now be quite accurately pre-determined.

It seems probable that, with some exceptions, it will not be an electrical factor that eventually limits the voltage, but rather an economical or natural one. For instance, the power naturally concentrated at a given point, as in a water fall, will generally be exceeded by the demand before the distance becomes so great that it is necessary to use voltages above the corona limit for economical transmission. Of course this does not mean that it is not necessary to consider the corona characteristics of the high voltage transmission line, and to properly proportion the conductors for any given case. Consideration of corona characteristics is generally of importance in lines above 66,000 volts.

Although the suspension insulator as at present designed, will be able to take care of transmission voltages for some time to come, it is important to look into the characteristics of the string of units in series with a view, possibly, of limiting line troubles, lessening the cost of line construction, etc.

In general, two arc-over voltages are specified in insulator tests: the rain arc-over voltage, and the dry arc-over voltage. For the same operating voltage, an insulator may give very good results, say in the Rocky Mountains, and not be satisfactory at all on the sea coast, due to surface leakage. This latter consideration, however, is beyond the scope of the present paper. The object of this paper is to show the general limiting features and characteristics of insulators in series, and the cause of these characteristics.

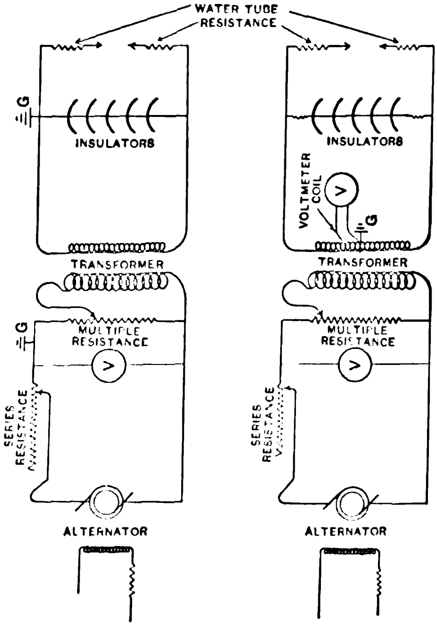

FIG. 1.

METHOD OF TEST

The tests below were made on various sizes of insulators of different manufacture. Connections were as in Fig. 1. Voltage was gradually increased on a single insulator unit and gap setting until a dynamic arc followed, either at the gap, or over the insulator. If the arc took place at the gap first, new needles were placed in the gap and the distance between points was increased. This was repeated until the insulator arced over before the gap. Thus by a number of such settings the arc-over voltage of the insulator was determined. Units were then added, one at a time, and the arc-over voltages of different lengths of string were determined in a similar manner. Table I shows a typical data sheet and is self-explanatory.

TABLE I

DRY ARC-OVER TEST

Insulators in series	Gap inches	Arc-over at	Gap at arc over
1	8	Gap	
1	9	Insulator	
1	8.4	Gap	
1	8.6	Insulator	8.5
2	18	Insulator	
2	17	Insulator	
2	16	Gap	
2	17	Gap	
2	17	Insulator	17
3	21	Gap	
3	22	Gap	
3	25	Gap	
3	26	Insulator	
3	25.8	Gap	25.9

Temperature: Wet bulb.......20 deg. cent.
Dry " ....22 deg. cent.
Barometer 74 cm.

No special difficulty should be experienced in getting consistent test data if the proper precautions are taken, of which the most vital ones are:

1. The needle points should be at a distance at least equal to the length of the gap, preferably twice the length of the gap, away from walls, etc. New needles should be used after each arc-over.

2. Water tube resistances should be placed in series with each needle. The resistances should be of such value that the short circuit current is between ¼ ampere and one ampere. The principal object of the resistances is to eliminate the discrepancies that would otherwise arise, due to oscillations caused by the spark and the inductance and capacity of the leads.

3. Care should be taken not to use generator field control of the voltage over too great a range and thus cause disturbances due to wave distortion and the unstable condition of a weak field. The same applies to the transformer. The potentiometer method of voltage control is best for careful work. By the potentiometer method is meant a variable resistance in series with the generator

for voltage change, and a multiple resistance, taking from three to ten times the exciting current across the low-voltage winding of the transformer. (See Fig. 1.) The object of the multiple resistance is to prevent wave distortion that would otherwise be caused by the series resistance. The shunt and series resistances also tend to dampen disturbances. The potentiometer method combined with field control will generally be found most convenient. It is often desirable to place some resistance in series with the test piece. In doing this, however, due regard should be given the following precaution.

4. The power available at the test piece should be sufficient to allow a true dynamic arc to start before an appreciable change can take place in voltage or wave form. Often a white snapping arc will start across the gap without " dynamic " following. This should not count as a measurement, as it is generally caused by some disturbance.

5. The test piece should not be allowed to become warm by arcing.

6. Temperature, barometric readings, frequency, and size of needle should always be noted.

7. In rain tests, the character of spray, amount and resistance of water, etc., should be carefully noted.

TEST ELECTRICAL CHARACTERISTICS

Fig. 2 shows the wet and dry arc-over voltages for different numbers of insulators in series. These are characteristic curves of the suspension insulator. Considering the dry test: one unit arcs over at 85 kilovolts, two units arc over *not* at 85 × 2 or 170 kilovolts, but at 140 kilovolts. Seven units arc over not at 7×85 or 595 kilovolts, but at 335 kilovolts. Thus, we cannot say that if it takes *e* volts to arc over one insulator, it will take *n e* volts to arc over *n* insulators. This is because the voltage along the string is not balanced, that is, the units do not share the voltage equally. The insulator next to the line takes more than its share and arcs over first, the others follow quickly in succession, and it generally appears as if the arc is simultaneous over the whole string. If voltage is gradually increased on a string of insulators in the dark, corona glow is first noticed around the cap on the line insulator, then as the voltage is gradually raised, corona appears successively on the second unit, third unit, etc., until arc-over occurs. It is also possible, at times, to get a "static snap " over the first insulator without arcing over the whole string. These tests show that the voltage is highest on the line insulator and gradually decreases on the units as the tower is approached. It is convenient in comparing the suitability of different types of units for connection together in a string to use the ratio of the actual arc-over voltage of *n* insulators to *n* times the arc-over voltage of one insulator. This may be called the *string efficiency*. Thus

$$\text{String efficiency} = \frac{\text{arc-over voltage } n \text{ insulators}}{n \times \text{arc-over voltage one insulator}}$$

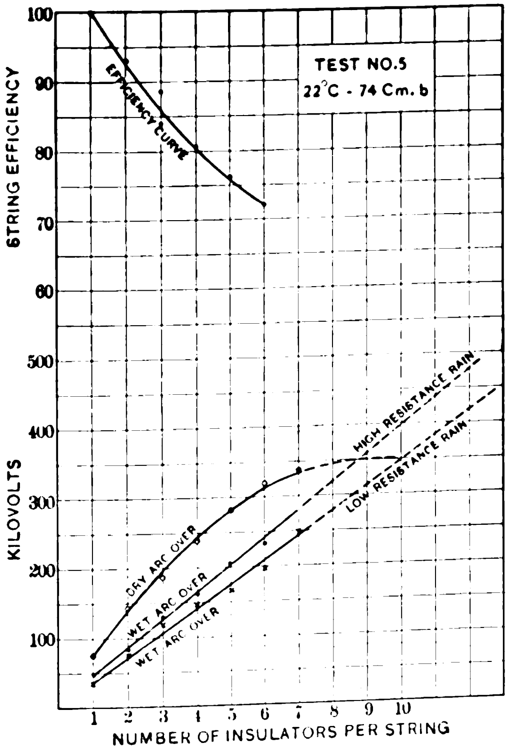

FIG. 2.—TEST CHARACTERISTIC CURVES OF SUSPENSION INSULATORS.

The efficiency curve is plotted in Fig. 2, and shows that the *string efficiency* rapidly decreases as the length of the string is increased. If the units are very close together arc-over will take place from line to tower. This will mean a low efficiency but not necessarily due to unbalance. A condition of this sort may sometimes be advantageous if balance is good.

The rain for the wet arc-over tests was obtained from nozzles that gave a heavy precipitation accompanied by a mist. The underside of the insulator was thus well dampened by the mist. The two rain curves show the difference due to the resistance of the water. There would probably be little difference in an arc-over test through a very wide range of conductivity of the water, with precipitation on top of the insulator only. With the above type of precipitation, however, where the insulator is dampened all over, the difference is marked. It is interesting to note the balancing effect the moisture has on the voltage distribution. The wet arc-over voltage of *n* units in series is about equal to *n* times the arc-over voltage of a single unit. This would not be the case if only the top of each unit were wet, as is shown by test six plotted in Fig. 3. These curves are plotted average volts per unit, that is, total arc-over volts divided by the number of units in series, as ordinate, and number of units in series as abscissae. The mist and rain curve where the insulator is wet all over shows that the voltage is balanced over each insulator. The curve for rain on top of insulator only

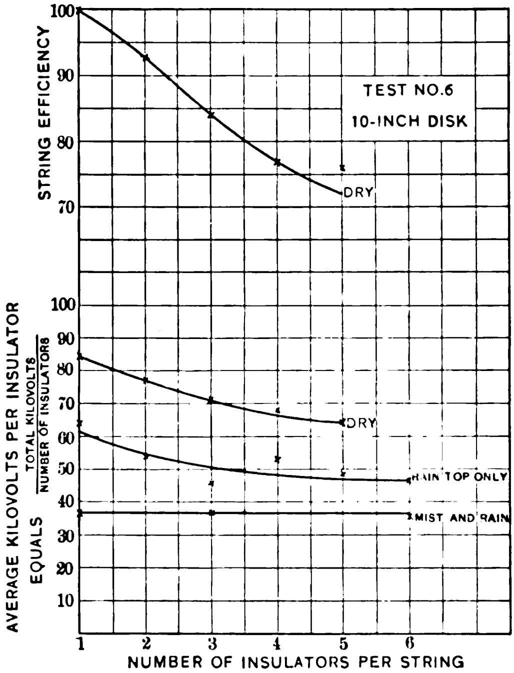

FIG. 3.—TEST CHARACTERISTIC CURVES OF SUSPENSION INSULATORS

shows unbalanced voltage similar to the dry test, except that the arc-over voltage is lowered. The moisture tends to balance the voltage because the leakage current is large compared with the capacity current. The action is somewhat similar to an auto-transformer across the string, with equal voltage taps connected to each unit. Note that due to the balancing, the wet and dry curves cross Fig. 2, and that after a certain number of units are placed in series, the wet arc-over voltage is greater than the dry arc-over voltage.

TABLE II. ARC-OVER TESTS

TEST NO. 1. INSULATOR NO. 1

DRY

No. of insulators	Kilovolts	Per cent efficiency
1	52	100
2	89	85.6
3	132	84.7
4	175	84.2
5	215	82.7
6	259	83
7	277	76
8	308	74
9	340	72.6
10	...	.....

TABLE III.

TEST NO. 2. INSULATOR NO. 2

DRY

No. of insulators	Kilovolts	Per cent efficiency
1	63	100
2	125	99.2
3	175	92.5
4	233	92.5
5	280	89.0
6	323	85.5
7	360	81.5

TABLE IV.

TEST NO. 3. INSULATOR NO. 3

DRY

No. of insulators	Kilovolts	Per cent efficiency
1	68	100
2	132	97
3	193	94.7
4	245	90
5	295	86.8
6	324	79.5
7	357	74.9

TABLE V

Test No. 4. Insulator No. 4.

DRY

No. of insulators	Kilovolts	Per cent efficiency
1	82	100
2	146	89
3	212	86.2
4	258	78.6
5	308	75
6	355	72.2
7		

TABLE VI

Test No. 5. Insulator No. 5

DRY

No. of insulators	Kilovolts	Per cent efficiency
1	74	100
2	137	93
3	186	84
4	238	80.5
5	281	76
6	318	72

TABLE VII

Test No. 5. Insulator No. 5

(HIGH-RESISTANCE RAIN WATER USED.)

No. of insulators	Kilovolts
1	45
2	81
3	126
4	161
5	204
6	234
7	248

TABLE VIII

Test No. 5. Insulator No. 5

(LOW-RESISTANCE RAIN WATER USED)

No. of insulators per string	Total kilovolts
1	39
2	72
3	118
4	146
5	162
6	196
7	244

TABLE IX

Test No. 6. Insulator No. 6

No. of insulators in series	Total kilovolts				Average kilovolts		
	Dry	Wet	Mist	Efficiency dry	Dry	Wet	Mist
1	84	64	37	100	84	64	37
2	154	108		93	77	54	
3	212	138	111	84	71	46	37
4	262	212		77	68	53	
5	320	244		76	64	49	
6	...	284	214	...	..	47	36

Fig. 4 shows arc-over and efficiency curves made on different insulators, the relative sizes of which are shown in Fig. 5. Note that (2) is the most efficient insulator (dry), and will actually stand higher voltages after seven or eight insulators are placed in the string, than the larger units. The relative magnitude of mutual capacity c_2, and the capacity to ground c_1, for the caps, can be seen from Fig. 6. The cause of unbalancing of voltage will appear in the section under theoretical characteristics, and

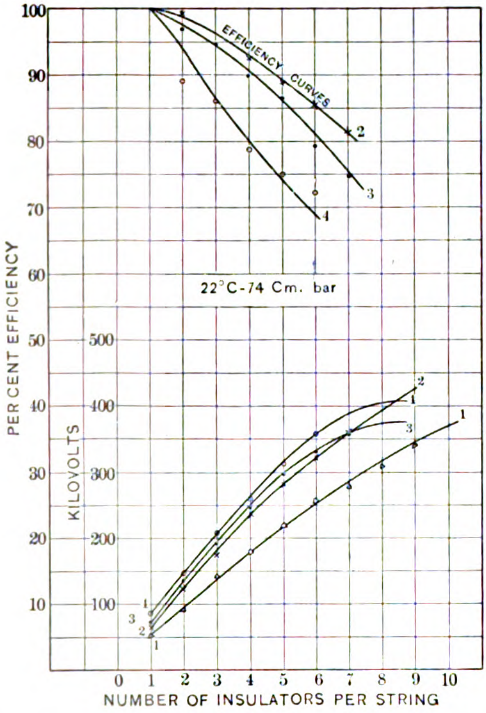

Fig. 4.—Test Arc-Over and Efficiency Curves for Different Sizes and Types of Insulators.

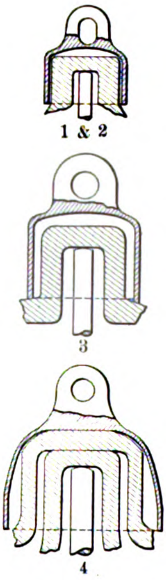

Fig. 6.

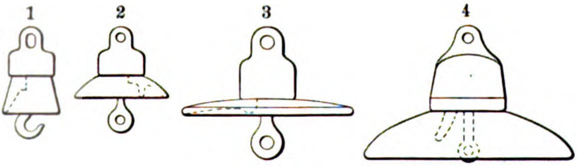

Fig. 5.

depends upon the ratio $\frac{c_2}{c_1}$. It seems that where it is necessary to use an insulator with larger leakage surface than (2), as in a damp country, (3) or (4) would be more practical, but could probably be greatly improved by increasing $\frac{c_2}{c_1}$, perhaps by a different type of caps and metal parts, or better spacing of units. The general experience in practice is that the insulator next to the line is the one most frequently damaged by lightning, etc. The reasons for this are obvious from a consideration of the tests above, and the theoretical data below.

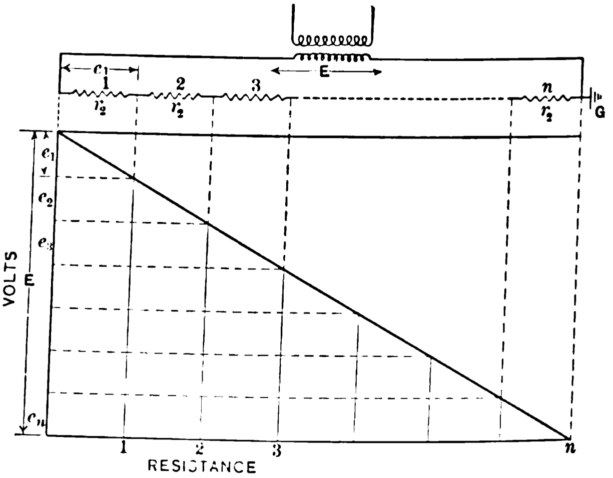

FIG. 7.

THEORETICAL ELECTRICAL CHARACTERISTICS

If a number of equal resistances are connected in series in a string as in Fig. 7, and voltage E is applied across the string, the total current is

$$i_t = \frac{E}{n\, r_2}$$

The voltage across each resistance is equal and is

$$e_1 = e_2 \ldots\ldots\ldots\ldots = e_n = i_t\, r_2$$

And

$$E = ne_1 = ne_2 \ldots\ldots = ne_n$$

If, now, a number of equal resistances, r_1, to ground are added as in Fig. 8, the current through the first resistance r_2, is

$$(i_t - i_1)$$

and the voltage across the first resistance is

$$e_1 = (i_t - i_1)\, r_2$$

The voltages across the succeeding resistances are

$$e_2 = (i_t - i_1 - i_2)\, r_2$$

$$e_3 = (i_t - i_1 - i_2 - i_3)\, r_2$$

$$e_n = (i_t - i_1 - i_2 \ldots\ldots\ldots\ldots - i_n)\, r_2$$

It is seen at once that the voltage across the first resistance is greater than the voltage across the second and so on. Also the greater the currents i_1, i_2, i_3, etc., are, the greater the unbalancing.

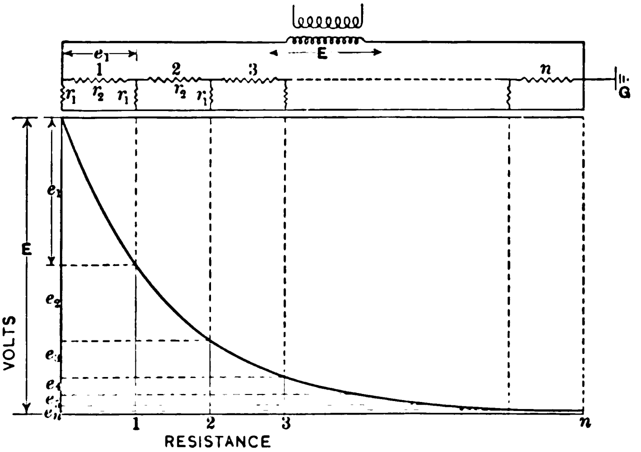

Fig. 8.

A quite similar condition exists in a string of insulators,* except that the resistance must be replaced by capacitance. Let Fig. 9 represent a string of suspension insulators grounded at one end, G, as at the tower. It is seen that each insulator may be represented as a condenser with a capacity c_2, and that each connecting link and cap may be represented as a condenser with a capacity c_1 to ground. Greater capacity current passes through insulator (1) than through insulator (2), etc., hence, the voltage across insulator (1) is greater than across insulator (2), etc., or, the voltage is not balanced along the string. The greater c_1 is compared with c_2 the greater the unbalancing. Also the greater the number of units in a string the greater is the unbalancing. The voltage across the different insulators of a given string can be readily calculated if the ratio $\frac{c_2}{c_1}$ is known, and it is assumed there is no surface leakage or corona. Leakage or corona will not appreciably affect the results at operating voltage.

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*The condition is also similar to that of multigap lightning arrester which has already been discussed in the Transactions.

Referring to Fig. 9 an expression for the total capacity of a string of n insulators may first be written.

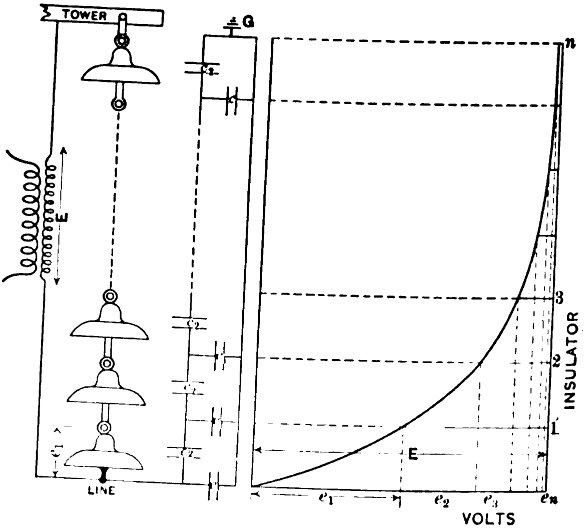

FIG. 9.

Capacity of string

Let $c_2 = x\,c_1$

Then the total capacity for a string of n insulators is

One insulator

$$k_1 = c_1 + c_2 = c_1\,(1 + x)$$

Two insulators

$$k_2 = c_1 + \frac{1}{\dfrac{1}{c_1 + c_2} + \dfrac{1}{c_2}} = c_2\left(\frac{1}{x} + \frac{k_1}{c_2 + k_1}\right)$$

$$= c_1 + c_2 - \frac{c_2^2}{2\,c_2 + c_1}$$

Three insulators

$$k_3 = c_1 + \frac{1}{\frac{1}{k_2} + \frac{1}{c_2}} = c_2\left(\frac{1}{x} + \frac{k_2}{c_2 + k_2}\right)$$

$$= c_1 + c_2 - \frac{c_2^2}{c_2 + k_2} = c_1 + c_2 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{2c_2 + c_1}}$$

For a string of n insulators

$$k_n = c_1 + c_2 - \frac{c_2^2}{c_2 + k_{n-1}} = c_2\left(\frac{1}{x} + \frac{k_n - 1}{c_2 + k_{n-1}}\right)$$

$$= c_1 + c_2 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{\cdots\ \overline{2c_2 + c_1}}}}}$$

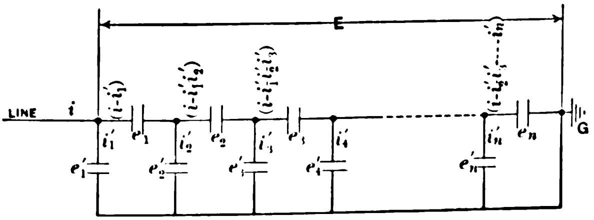

FIG. 10.

The fraction to be carried out to $n - 1$, of the $(2\ c_2 + c_1)$ terms.

Voltage Distribution. Let E be the voltage across the string to ground. (See Fig. 10.)

Also

i_t = total capacity current.

$x = \frac{c_2}{c_1}$ c_2 = mutual capacity
c_1 = capacity to ground

k_n = total capacity of the string.

$k = \frac{k_n}{c_1}$

Then
$$i_t = 2\,\pi\,f\,k_n\,E$$
$$i_1 = 2\,\pi\,f\,c_1\,E$$

Then the voltage across the first or line insulator is

$$e_1 = \frac{i_t - i_1}{2\,\pi\,f\,c_2} = \frac{2\,\pi\,f\,E\,(k_n - c_1)}{2\,\pi\,f\,c_2}$$

$$= E\,\frac{(k_n - c_1)}{c_2} = \frac{E}{x}\,(k - 1)$$

The voltage e_2 across the second insulator is found thus:

$$e_2' = E - e_1 = E\left(\frac{x - k + 1}{x}\right)$$

$$i_2 = 2\,\pi\,f\,e_2'\,c_1 = 2\,\pi\,f\,c_1\left(\frac{x - k + 1}{x}\right)E$$

Therefore

$$e_2 = \frac{(i_t - i_1 - i_2)}{2\,\pi\,f\,c_2} = E\,\frac{k(x + 1) - (2x + 1)}{x^2}$$

$$= \frac{E}{x}\left(k - 2 + \frac{k - 1}{x}\right) = e_1 - \frac{e_2'}{x}$$

For the third insulator

$$e_3 = E\,\frac{x\,(x + 1)\,(k - 1) + (2x + 1)\,(k - 1) - x\,(x + 1)}{x^3}$$

$$= \frac{E}{x}\left(k - 3 + \frac{3k - 4}{x} + \frac{k - 1}{x_2}\right) = e_2 - \frac{e_3'}{x}$$

For the *nth* insulator

$$e_n = \frac{E}{x}\left(k - n + \frac{\quad}{x} + \frac{\quad}{x_2} + \qquad + \frac{k - 1}{x^{n-1}}\right) = e_{n-1} - \frac{e_n'}{x}$$

Then we may write

$$e_1 = \frac{E}{x}\,(k - 1) \quad \text{first insulator}$$

$$e_2 = e_1 - \frac{e_2'}{x} = \frac{E}{x}\,k - 2 + \frac{k - 1}{x} \quad \text{second insulator}$$

$$e_3 = e_2 - \frac{e_3'}{x} = \frac{E}{x}\left(k - 3 + \frac{3k-4}{x} + \frac{k-1}{x_2}\right)$$ third insulator

$$e_4 = e_3 - \frac{e_4'}{x} = \frac{E}{x}\left(k - 4 + \frac{6k-4}{x} + \frac{5k-6}{x^2} + \frac{k-1}{x^3}.\right)$$ fourth insulator

$$e_5 = e_4 - \frac{e_5'}{x} = \frac{E}{x}\left(k - 5 + \frac{10k-14}{x} + \frac{15k-15}{x^2} + \frac{7k-8}{x_3} + \frac{k-1}{x_4}\right)$$

$$e_n = e_{n-1} - \frac{e_n'}{x} = \frac{E}{x}\left(k - n + \frac{\quad}{x} + \frac{\quad}{x^2} + \dots \frac{k-1}{x^{n-1}}\right)$$

From the above the following equations may be written for solving numerical problems.

Total capacity of a string of n insulators

1. $$k_n = c_1 + c_2 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{2c_2 + c_1 - \cfrac{c_2^2}{\cfrac{\quad}{\cfrac{\quad}{2c_2 + c_1}}}}}$$

Write fraction to $n - 1$ of the $2c_2 + c_1$ terms.

2. Volts across first or line insulator of string of n is

$$e_1 = \frac{E}{x}(k - 1)$$

$$k = \frac{k_n}{c_1}$$

3. The voltage across the m th insulator of a string is

$$e_m = e_{m-1} + \frac{e_{m-1} + e_{m-2} + \dots\dots\dots\dots + e_1 - E}{x}$$

4. $$E = \frac{e_1 x}{k - 1}$$

When the arc-over voltage of a single unit alone e_a is taken for e_1

4a. $$E_a = \frac{e_1\,x}{(k-1)} = \text{arc-over voltage of string.}$$

5. String efficiency $$= \frac{E_a}{n\,e_a} = \frac{x}{n\,(k-1)}$$

CALCULATED CHARACTERISTICS

It is now interesting to calculate the characteristics of insulators in series, for different lengths of string, and different values of $\frac{c_2}{c_1}$, using formulas 1, 2, 3, 4, and 5.

TABLE X

Ratio c_2/c_1	1	2	5	10	15	20	50	100	500	1000
No. of insulators in series					Value	s of K				
1	2.000	3.000	6.000	11.000	16.000	21.000	51.000	101.00	501.00	1001.00
2	1.667	2.200	3.728	6.238	8.742	11.244	26.247	51.21	251.25	501.25
3	1.625	2.048	3.135	4.842	6.387	8.197	18.998	34.89	173.22	334.89
4	1.619	2.012	2.927	4.263	5.546	6.814	14.350	26.87	126.87	251.87
5	1.618	2.003	2.846	3.988	5.049	6.083	12.172	22.20	102.20	202.20
6	"	2.001	2.814	3.851	4.777	5.676	10.777	19.19	85.83	169.29
7	"	2.000	2.801	3.781	4.623	5.421	9.863	17.15	74.36	145.82
8	"	"	2.795	3.743	4.574	5.265	9.238	15.69	65.68	128.18
9	"	"	2.793	3.724	4.505	5.178	8.797	14.63	59.03	114.63
10	"	"	2.792	3.713	4.465	5.108	8.481	13.85	53.85	103.85
11	"	"	"	3.708	4.447	5.069	8.251	13.23	49.68	95.09
12	"	"	"	3.705	4.415	5.044	8.083	12.84	46.22	91.85
13	"	"	"	3.703	4.411	5.036	7.958	12.52	43.29	81.75
14	"	"	"	3.702	4.409	5.024	7.865	12.33	40.93	76.58
15	"	"	"	3.702	4.407	5.015	7.796	12.17	38.81	72.21

To find the total capacity of the string, k_n, take the k above for the required ratio $\frac{c_2}{c_1}$, and the given number of insulators in series and multiply by c_1.

$$K_n = k c_1$$

As an example of use of formulas, assume

$$\frac{c_2}{c_1} = \frac{5}{1} = x$$

$$n = 3 \qquad E = 100 \qquad k = \frac{k_n}{c_1}$$

$$\text{From (1) } k_n = c_1 + c_2 - \cfrac{c_2^2}{2\,c_2 + c_1 - \cfrac{c_2^2}{2\,c_2 + c_1}}$$

$$= 1 + 5 - \cfrac{25}{10 + 1 - \cfrac{25}{10 + 1}} = 1 + 5 - \frac{25}{11 - 2.27} = 3.135$$

$$\text{From (2) } e_1 = \frac{E}{x}\,(k - 1)$$

$$= \frac{100}{5}\,(3.135 - 1) = 42.7$$

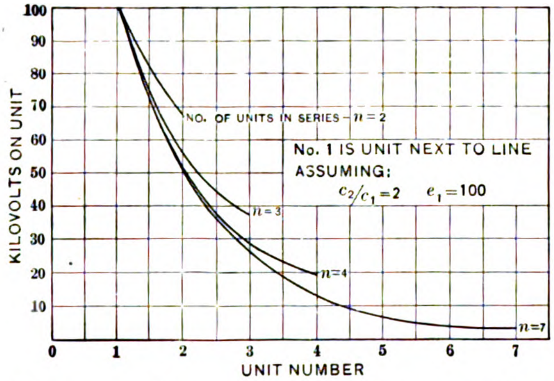

FIG. 11.—CALCULATED VOLTAGE ACROSS DIFFERENT INSULATORS IN A STRING OF *n* UNITS.

$$\text{From (3)} \qquad e_2 = e_{2\cdot 1} + \frac{e_{2\cdot 1} - E}{x} = e_1 + \frac{e_1 - E}{x}$$

$$= 42.7 + \frac{42.7 - 100}{5} = 31.3$$

$$e_3 = \left(31.3 + \frac{31.3 + 42.7 - 100}{5}\right) = 26$$

$$E = e_1 + e_2 + e_3 = 100$$

Figs. 11 and 15 are calculated for 100 kilovolts across the line insulator (1). Looking at Fig. 11 for a string of three insulators and the ratio $\frac{c_2}{c_1} = 2$

$$e_1 = 100$$
$$e_2 = 55$$
$$e_3 = 37$$

Hence, the total voltage across the string is $e_1 + e_2 + e_3 = 192$ It is convenient to plot these curves so that e_1 is the arc-over voltage of a single unit, because when (1) in a given string is brought to its arc-over voltage, flash over will take place and the other units follow in succession and complete arc-over occurs. Hence, if 100 kilovolts is the arc-over of a single unit alone, 192 is the arc-over voltage of the string of three units above.

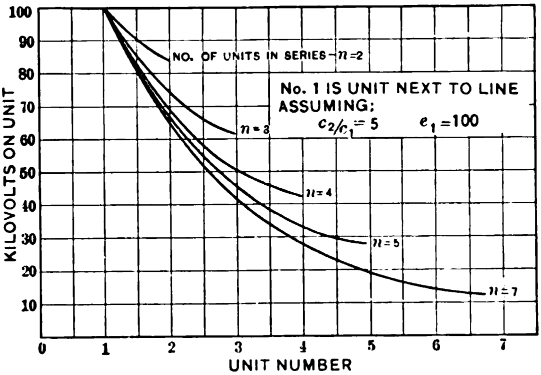

FIG. 12.—VOLTAGE ACROSS DIFFERENT INSULATORS IN A STRING OF n UNITS.

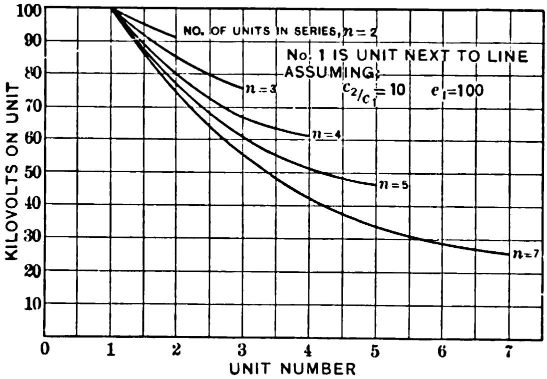

FIG. 13.—VOLTAGE ACROSS DIFFERENT INSULATORS IN A STRING OF n UNITS.

The string efficiency as defined under section on Test Characteristics for the three units above is

$$\text{Efficiency} = \frac{192}{3 \times 100} = 0.64$$

The above curves may be used for finding the string arc-over for any other value than 100 for single unit arc-over by reducing e_1, e_2, e_3, etc., in proportion.

Fig. 16 gives calculated values of total arc-over voltage for different numbers of insulators in series, and is similar to the test curves. Fig. 16 is obtained either by summation of e_1, e_2, ... e_n from Figs. 11 to 15, or by equation (4), and is based on 100 kilovolts arc-over for a single unit.

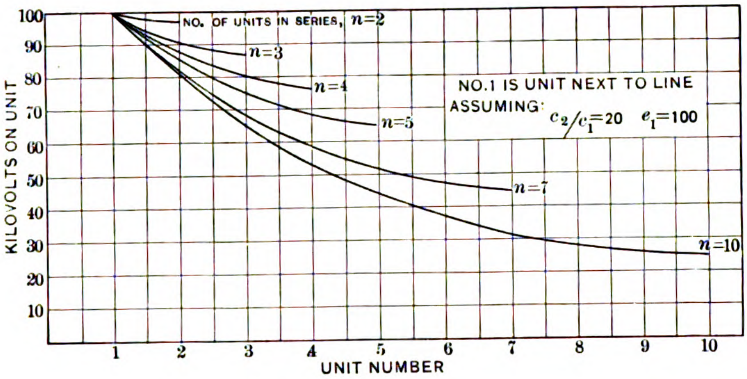

FIG. 14.—VOLTAGE ACROSS DIFFERENT INSULATORS IN A STRING OF n UNITS.

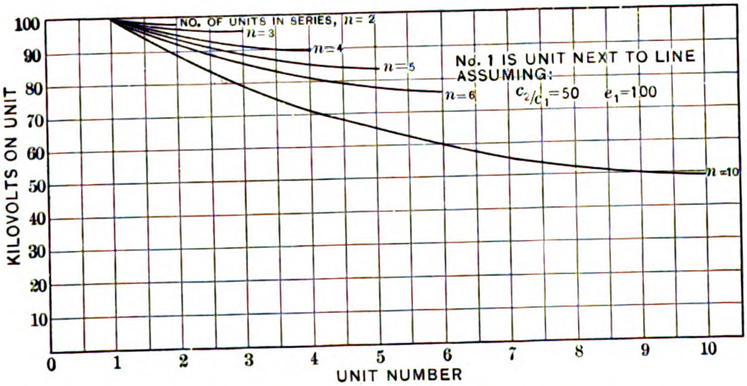

FIG. 15.—VOLTAGE ACROSS DIFFERENT INSULATORS IN A STRING OF n UNITS.

Fig. 17 gives calculated efficiencies as defined above.

It is to be noted that while, theoretically, when reactance and resistance are not appreciable, frequency does not enter into the voltage distribution, at the high voltages, where surface leakage or corona starts, and at arc-over, frequency would be a factor. Thus, for very long strings of small insulators it might be possible to arc-over the insulators near the line without arcing over the whole string, due to the fall of potential over the arc resistance. This resistance would vary with the frequency. At very high frequency it is necessary to consider reactance. Before surface leakage starts, as at operating voltages, the distribution should be substantially as given in curves 11 to 15. As the voltage is increased, corona forms first on the line insulator, and probably generally increases the mutual capacity c_2 without materially changing c_1. In this way a sort of automatic grading takes place, and the distribution by arc over often indicates a much better distribution than exists at operating voltage. Hence, it seems that the arc-over would not always indicate the best insulators for all conditions of service. As, for instance, with surge, sudden impulse, lightning, or transient voltages, a bad operating distribution would probably mean not flash over, but punctured porcelain, or, the porcelain would puncture before corona could form, to better distribute the stress. In selecting an insulator, therefore, it would probably be best to specify a certain arc-over voltage and string efficiency.

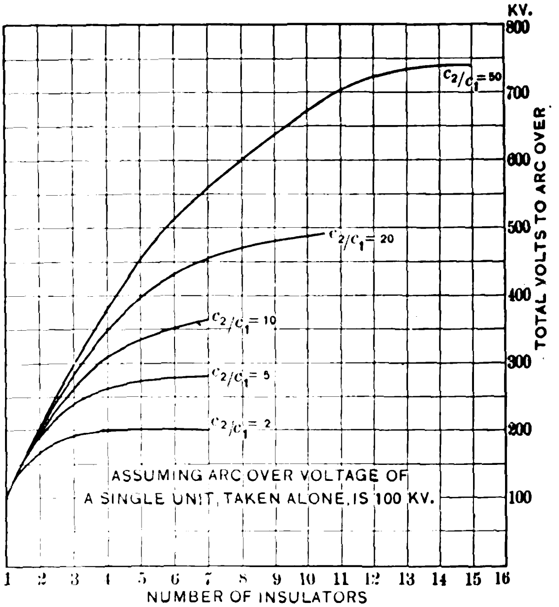

FIG. 16.—CALCULATED ARC-OVER VOLTS OF *n* INSULATORS IN SERIES.

COMPARISON OF TEST CHARACTERISTICS AND THEORETICAL CHARACTERISTICS

In Fig. 18 the drawn curve is the theoretical one for $\frac{c_2}{c_1} = 50$, and the condition that a single unit arcs over at 63 kilovolts. This is the test arc-over voltage of a single unit in Test 2. The crosses are measured arc-over readings. The test values follow the theoretical curve rather better than would be expected, and seem to indicate little change in $\frac{c_2}{c_1}$ due to corona, and small leakage up to the flash-over point for this particular insulator.

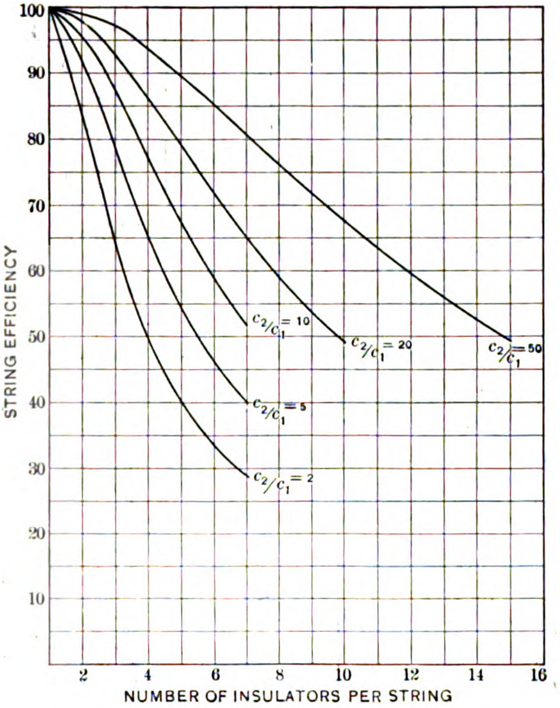

FIG. 17.—CALCULATED STRING EFFICIENCY.

In Test 5 the arc-over voltage of a single unit is 74 kilovolts. The drawn curves in Fig. 19 are the theoretical ones for that condition, and $\frac{c_2}{c_1} = 10$, $\frac{c_2}{c_1} = 15$, and $\frac{c_2}{c_1} = 20$. The crosses are the measured values. This quite nicely shows the effect of automatic grading due to corona and leakage. For short strings the points follow the curve for $\frac{c_2}{c_1} = 10$, which, if continued, would give a very low flash-over efficiency. Automatic grading comes in and the points gradually shift up to the curve for $\frac{c_2}{c_1} = 20$. The actual value of $\frac{c_2}{c_1}$ under operating voltage is probably between 5 and 10. Thus; while arc-over tests for long strings may indicate a fair efficiency, the insulator is really operating at a very bad unbalance of voltage. This is further indicated by Fig. 20, for Test 4.

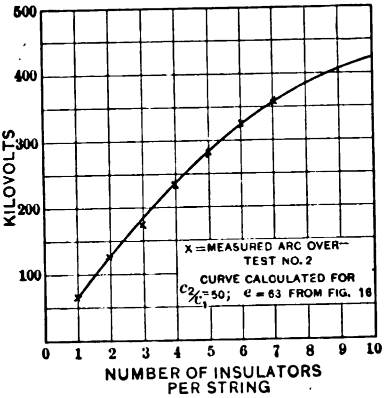

FIG. 18.—COMPARISON OF CALCULATED CURVES AND TEST CURVES.

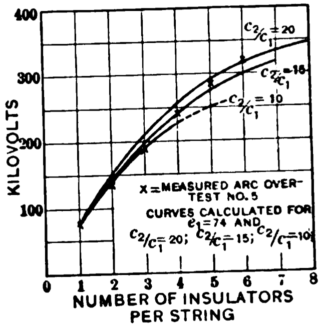

FIG. 19.—COMPARISON OF CALCULATED CURVES AND TEST CURVES.

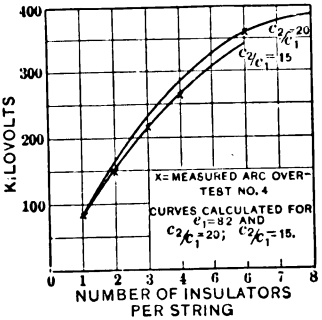

FIG. 20.—COMPARISON OF CALCULATED CURVES AND TEST CURVES.

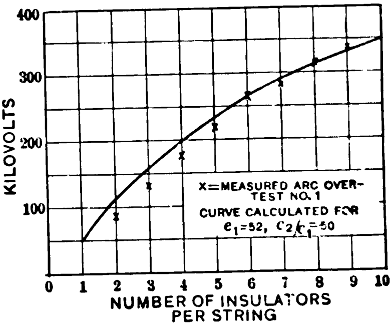

FIG. 21.—COMPARISON OF CALCULATED CURVES AND TEST CURVES.

The theoretical curves given in Figs. 11 to 17 will be found useful in comparing and studying test values. For instance, the curves in Fig. 16 are calculated for total arc-over voltage of n insulators for different values of $\frac{c_2}{c_1}$, and arc-over voltage of 100 kilovolts for a single unit alone. Where the arc-over voltage of a single unit differs from 100 kilovolts, and is, say 63 kilovolts, the curves may be used for graphical calculations by multiplying the ordinates by 0.63. The tabulated values of K may also be used for obtaining the string capacity K_n with minimum calculation.

CONCLUSIONS

1. An insulator taken as an individual unit may show very excellent characteristics, but, on account of certain inherent relations between mutual capacity and capacity to ground, be totally unfit for use in series.

2. The arc-over voltage test of insulators in series does not always indicate the best insulator, but should be supplemented by a study of corona formation in the individual units along the string. To this should be added a comparison of theoretical and arc-over efficiency curves.

3. Where the mutual capacity, c_2 is small compared with to ground capacity, c_1, after a certain number of insulators are added it is useless to increase the string length. For very high voltages insulation will probably not be obtained by long strings but rather by shorter strings of well-designed and properly spaced units; grading may also be resorted to. The arc-over voltage may often actually be increased in a given design by decreasing spacing between units. In selecting insulators, a good string balance or efficiency should be sought or specified. Without good balance the line insulator is likely to be punctured by lightning or surge.

4. The voltage balance along a string will be affected by the distance to the tower, etc.

5. The arc-over voltage will generally decrease as the frequency is increased, due to leakage. It will also decrease as temperature is increased and barometric pressure is decreased.

6. The wet arc-over voltage will vary greatly with the resistance and temperature of the rain and the nature of the spray. The wet arc-over voltage may actually be greater than the dry arc-over voltage after a certain critical length of string is reached.

7. The arc-over test voltage on long strings will vary some-

what with the transformer connection, that is, whether one side of the transformer is grounded or not. One side of the transformer should be grounded to approximate practical conditions.

8. Insulator arc-over tests are valueless unless proper test precautions are taken to eliminate resonance, etc., and full data are given.

Thanks are due to Professor C. E. Magnusson of the University of Washington for his valuable assistance in the tests, equations and calculations, and to the Consulting Engineering Department of the General Electric Company for the facilities afforded.

A paper to be presented at the Schenectady Meeting of the American Institute of Electrical Engineers, Schenectady, N. Y., May 17, 1912.

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(*Subject to final revision for the Transactions.*)

FREIGHT TRAIN TESTS ON AN ELECTRIC INTERURBAN RAILWAY

BY S. T. DODD

The following article is a brief discussion of a series of tests made upon electric locomotives pulling freight trains on the Fort Dodge, Des Moines & Southern Railway, and a tabulation of the results of those tests. The object of the tests was to obtain records under regular service conditions from which values could be calculated upon power consumption, train resistance, acceleration, and other fundamental data, which could be used to check the figures ordinarily assumed in making calculations and to show the amount of variation from standard figures which could be anticipated in practice.

TRAFFIC CONDITIONS

The Fort Dodge, Des Moines & Southern Railway is an interurban road running from Des Moines to Fort Dodge, Iowa, with a branch to Rockwell City. There are in all about 120 miles (193 km.) of electrified track of which a little over one-half is operated at 1200 volts. A map of the line is shown in Fig. 1. Fig. 2 shows a condensed profile of the section of the road from Boone to Fort Dodge, being the section over which the test trains were run. Distances given on the profile are in miles measured from the southern end of the line at Des Moines.

Having been built originally on a steam railroad franchise, the road is almost entirely on private right-of-way and the alignment is remarkably straight for an electric road. The greater part of the line is over rolling country with a series of short grades and level stretches, the maximum grade reached on this section being 1.1 per cent. There are two relatively short sections of the road where greater irregularities are to be found. These are the points where the line crosses the Des Moines river, between mileposts 46 and 53 and between mileposts 80 and 83.5. At these two points very irregular track

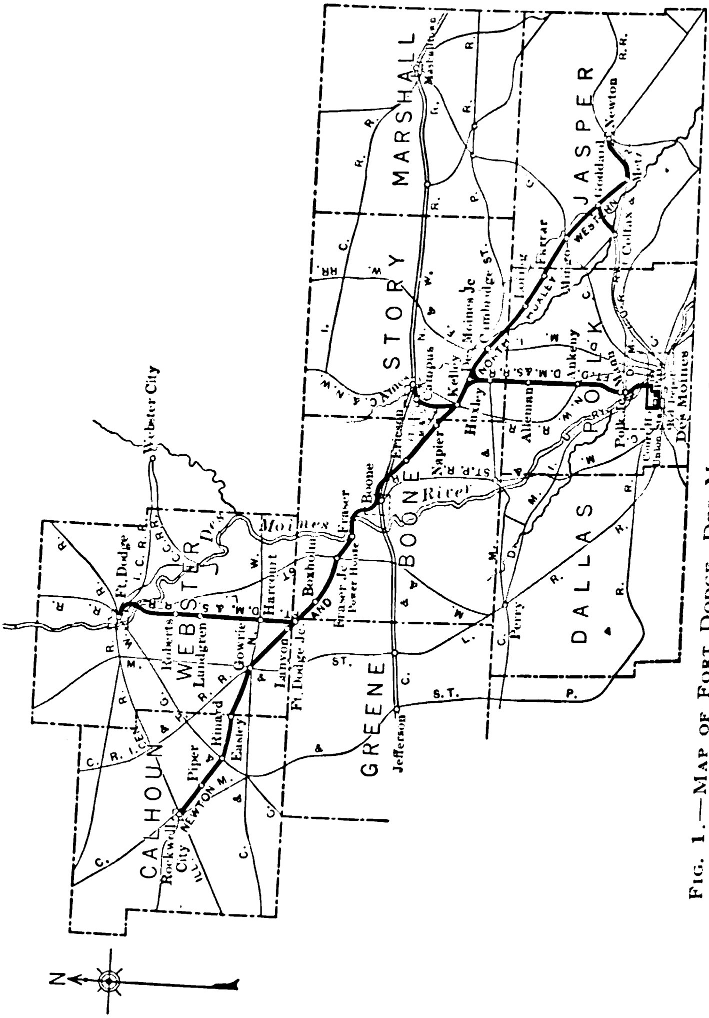


Fig. 1.—Map of Fort Dodge, Des Moines & Southern Railroad.

conditions are encountered with curves of 8 to 10 deg. and grades running as high as 2.44 per cent.

The road running as it does, in a general north and south direction crosses the main direction of the transcontinental traffic and intersects a number of important trunk lines including the C. R. I. & P. Ry., the C. & N. W. Ry., the I. C. RR., and others with which it interchanges traffic. The regular freight train each day goes down the line, stopping at each of these interchange points to set out cars and pick up cars for other points or for the terminus. Regular freight service consists, therefore, of a series of runs, 5 to 10 miles in length with a certain amount of switching service at each stop. In addition to this regular freight service, is a large amount of switching service at the terminals and some extra or through freight.

Electric Equipment and Motive Power

The section of the line over which the tests were run is operated at 1200 volts direct current (1,300 volts at substation), some 600-volt sections being encountered at Boone, Fort Dodge and Fraser. Power is delivered to the line from substation distributed and equipped as follows:

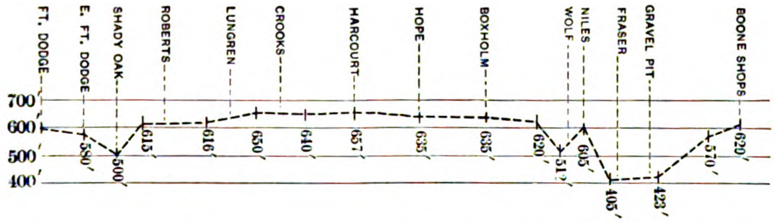


FIG. 2.—PROFILE OF F. D., D. M. & S. R.R., BOONE TO FORT DODGE.

Boone	600 volts.
Fraser	1200 volts and 600 volts.
Rinard	1200 volts.
East Fort Dodge	1200 volts and 600 volts.

Motive power consists of five 40-ton electric locomotives equipped for operation on either 600-volt or 1,200-volt lines. There are in addition two locomotives which have been rebuilt by the railway company, and equipped with similar motor equipment, and three locomotives suitable for working on 600-volt lines only and which are used in the 600-volt yards at the terminus.

Testing Outfit

The set of instruments used for carrying out the series of tests were all mounted in a box car and suitably wired up to flexible leads extending from one end of the car and ending in terminals by which they could be easily and quickly connected in the circuit of the locomotive to which the car was coupled. Figs. 3 and 4 show the interior of the test cars and the arrangement of instruments.

The set of instruments used consisted of the following.

One direct-current direct-reading voltmeter reading to 1,500 volts.

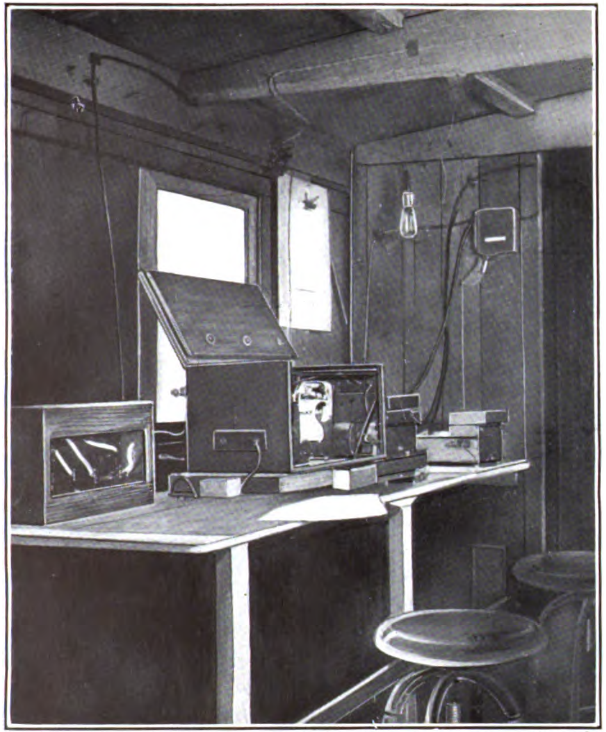
One direct-current direct-reading ammeter reading to 300 amperes.

One graphic recording voltmeter and one graphic recording ammeter of the same capacities as the direct reading instruments, with time marker clock and auxiliary marker pen indicating revolutions of the car wheel.

One railway type direct-current recording watthour meter mounted on shock absorbing base with a capacity of 1,200 volts and 600 amperes.

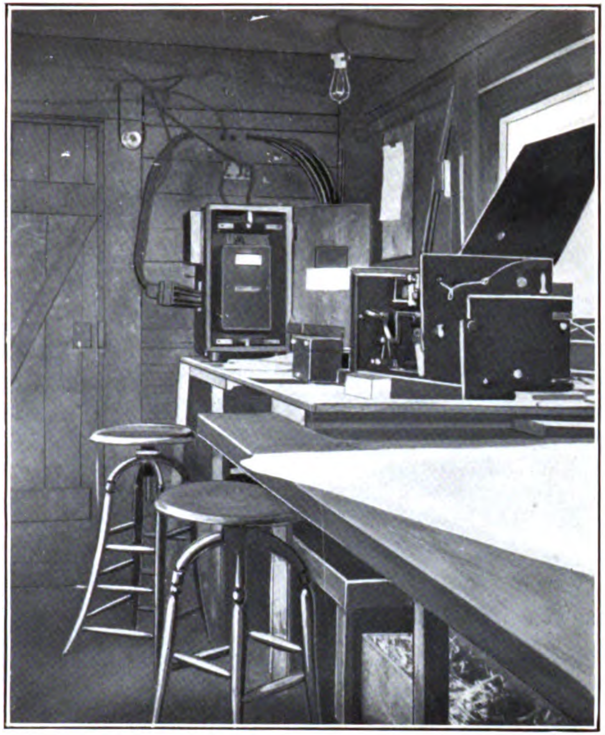
The wiring was arranged so that the integrating wattmeter and the voltmeter were connected in the main trolley circuit of the locomotive and read the total voltage and watts delivered at tbe trolley wheel. The ammeters were connected in the circuit of one motor only, in order that the current readings might be translated directly into terms of tractive effort without reference to the controller position. If, on the other hand, the current readings had indicated the total current in the locomotive it would be necessary to observe whether the controller was on the series or parallel notches and whether the locomotive was running on a 600-volt or a 1,200-volt section of the line, in order to obtain a correct expression for tractive effort. It was assumed in all the readings that the current in all motors was the same at the same instant. This is true under ordinary conditions due to the balanced combinations obtained by the bridge control. An exception will be noted when one pair of wheels slips in rounding curves or on slippery bits of track, throwing all the load on the other pairs. Some instances of this were noted during the tests, but except for such intermittent conditions, the assumption that total tractive effort can be read direct from current per motor is probably fairly accurate.

In preparation for a test, the car would be coupled to a train just back of the locomotive and the leads connected into the appropriate fuse block terminals. To make a complete test and obtain satisfactorily all the records, five observers were required whose duties were approximately as follows:



[DODD]

FIG. 3.—INTERIOR OF TEST CAR.



[DODD]

FIG. 4.—INTERIOR OF TEST CAR.

One man watched the recording ammeter, and a second the recording voltmeter. These observers maintained accurately the speed and excitation of the instruments, and made notes upon the record sheet which would tie together the various sets of observations.

A third man noted, by means of an auxiliary marker pen, the instant of passing given points such as stations, changes in grade, or other easily recognized points, and also took readings of the integrating wattmeter at points where changes in grade or character of traffic made these readings advisable.

A fourth man kept track of the train weight and his particular duty was to keep record at each station of the amount of switching and train movement.

The fifth man kept the log, keeping a continuous record of the time of all events, readings, notes, etc., which were reported to him by the other observers.

The test runs made by this testing car and crew were five in number. Table I gives in condensed form the logs of these tests, giving the chief facts as to stations between which runs were made and amount of time used for switching or waiting for connections. In this table weights refer to gross tonnage including weight of locomotive and test car. The figures in parentheses give the location of the station in miles from Des Moines at the southern end of the line.

Figs. 5, 6, and 7 are samples of the record sheets obtained in these tests. The curves on the lower section of each sheet show the current per motor and the total voltage. The curves on the upper section show the tractive effort of the whole locomotive as calculated from the current curves, and the speed in miles per hour.

Fig. 5 is a record obtained in Test Run 4 with a train of 752 tons gross weight running steadily over a broken profile. Figs. 6 and 7 show the same train on an up grade. Comment on these curves is hardly necessary as the course of events can be read directly from the record. The train is stalled at pole 2167 due to the slipping of the drivers. The locomotive takes the forward half of the train (373 tons) up the 1.5 per cent grade as far as pole 2213 where on a piece of slippery track the drivers begin slipping and it is necessary to back down to the starting point. At the second attempt the train is pulled through to the summit of the grade (pole 2227) although it will be noted the wheels slip again at the same piece of slippery track. The locomotive then

TABLE I
CONDENSED LOG OF TESTS

Test Run No. 1, Sept. 23, 1911

Time	From	To	Train Wt.	Remarks
1:7 P.M.	Fraser (51)	Niles (53)	192	Up 2.44 % grade. Switching at Niles.
1:42	Niles (53)	Boxholm (59)	532	Switching and connections.
2:43:30	Boxholm (59)	Hope (63)	532	Switching.
3:11	Hope (63)	Crooks (71.5)	313	Connections.
3:47	Crookes (71.5)	E. Ft. Dodge (83.5)	313	Switching.
4:41	E. Ft. Dodge (83.5)	Ft. Dodge (86)	70	
4:50				Ft. Dodge.

Test Run No. 2, Sept. 23 and 24, 1911

Time	From	To	Train Wt.	Remarks
10:7 P.M.	E. Ft. Dodge (83.5)		730	Two locomotives, mult. unit.
10:21:30				Stopped to cut train on 1.5 % grade.
10:31			407	Start on 1.5% grade
10:57			420	Start on 1.5 % grade.
11:16:30	Summit (80)	Roberts (78.5)	730	Drop one loco.
11:30	Roberts (78.5)	Harcourt sw. (68)	689	Switching.
12:40 A.M.	Harcourt sw. (68)	Harcourt (67)	353	Switching.
1:14	Harcourt (67)	Hope (63)	493	Switching.
1:56	Hope (63)	Boxholm (59)	491	Orders.
2:18	Boxholm (59)	Niles (53)	491	Switching.
2:52	Niles (51)	Boone (43.5)	351	
3:50				Boone shops

Test Run No. 3, Sept. 30, 1911

Time	From	To	Train Wt.	Remarks
3:55	Fraser (51)	....	600	Run of 4 miles of which 1 mile is up 1% grade toward Boone.

Test Run No. 4, Oct. 2, 1911

Time	From	To	Train Wt.	Remarks
1:19 A.M.	Fraser (51)	Niles (53)	327	Up 2.44 % grade Switching at Niles.
2:25	Niles (53)	....	752	
3:26	....	Harcourt (67)	...	Hot box 35 min. delay.
4:3	Harcourt 67)	....	752	
4:32	....	Lundgren (74.5)	...	Hot box 17 min. delay.
4:49	Lundgren (74.5)	....	752	
5:15	....	Ft. Dodge Hill (82)	...	Stop to cut train on 1% grade.
5:18	Ft. Dodge Hill (82)	E. Ft. Dodge (83.5)	373	Start on 1% grade.
5:56	Ft. Dodge Hill (82)	E. Ft. Dodge (83.5)	435	Start on 1% grade.
6:4				E. Ft. Dodge.

Test Run No. 5, Oct. 3, 1911

Time	From	To	Train Wt	Remarks
6:57	E. Ft. Dodge (83.5)	Summit (80)	420	Up 1.5% grade.

returns for the rear half of the train (435 tons) and pulls it through successfully at the first trial. Attention is called to this as it illustrates the variations in the hauling capacity of the same locomotive as affected by varying track conditions.

TRAIN FRICTION

An inspection of the test records shows a continually varying tractive effort corresponding to variations of grade, curvature and speed. No tests were made with the particular end in view of obtaining train friction but a number of readings have been selected from the record in order to obtain a value of train friction, at points where a fairly constant speed and current show that the effect of acceleration is eliminated. This value of train friction is not presented with a view of comparing in accuracy with the elaborate formulas and curves on freight car resistance which have been worked out by several steam railroads and which take into account the effect of speed, weather, temperature and other conditions, but it is presented as representing the average conditions during our tests and is to be accepted for comparative purposes only. It does possibly illustrate the variation in train friction and the values which may be expected in cars as picked up along interurban lines and possibly illustrates this better than the more elaborate formulas I have referred to. The following table summarizes the results:

TABLE II

TRAIN FRICTION

Test Run No. 1	average of five readings	5.54 lb.*
" " No. 2	" " " "	8.9 "
" " No. 3	" " three "	9.6 "
" " No. 4	" " ten "	5.96 "
" " No. 5	" " two "	7.3 "
Summary of 25 readings		7.0 lb.

* 1 lb. =0.45 kg.

CURVE AND GRADE RESISTANCE

The records were inspected with the hopes of ascertaining a value of the increased train resistance due to track curvature. Unfortunately no uniform results could be obtained. As said above, the track is in general straight, with easy curves, and the increased train resistance, due to a part of the train being upon a curve was masked by other variable conditions. On the approaches to the Des Moines river valley where a combination of grades and curves was encountered the tractive effort was so variable that it cannot be expressed by a definite formula. The track curves are not compensated and the surging of the train set up by track variation and attested by the general impression obtained from riding upon and watching the train was shown very clearly by the periodic variation or pulsation of the tractive effort shown on the record. Table III is a tabulation of the tractive effort on such portions of the track. It gives for a number of points the maximum and minimum values of the tractive effort and the amount of the variation expressed in percentage, and in the last column gives the variation in apparent train resistance, the appropriate amount for the corresponding grade having been deducted.

I have omitted from this table the results from tests No. 1 and No. 3. The results of test No. 1 are not as reliable as succeeding tests on account of voltage fluctuations during the run and also on account of the inexperience of the observers during the first test. Test No. 3 was made on the 1 per cent grade from Fraser to Boone where the curves are compensated at a rate of 0.04 per cent for each degree of curvature. Either for this reason or because it was raining heavily during the test, which would result in a certain amount of track lubrication, the fluctuation of tractive effort which appears in other tests is not evident in this one.

An average of all the results of Table III, giving to each one the same weights, shows an average train friction 13.4 lb. (6.1 kg.) per ton and a variation of train resistance above and below the average value of 15.8 per cent. In other words it seems to be indicated by these tests that in figuring train resistance on tracks of this nature where a combination of grades and curves are encountered, it is fair to assume that the train resistance is doubled and to allow a variation in total train resistance of approximately 15 per cent. above and below the average calculated value to compensate for surging set up in the train.

Power Consumption

As previously remarked, records were taken of the amount of movement and weight of train handled in switching service.

One of the observers was intrusted with the particular duty of noting during switching movements, each movement of the train and approximately the tonnage handled, estimating the tonnage from the number of cars and their condition as to load, and estimating the distance traveled from rail lengths or dis-

TABLE III.—TRAIN FRICTION ON CURVES

Time	Curvature	Grade	Speed	Train weight	Tractive effort		Variation from average	Grade resistance	Train friction
					Total	Lb. per ton			
	degrees	per cent.	mi. per hr.	tons			per cent		
				Test Run No. 2. Sept. 24, 1911					
10:34	4	1.5	6.5	407	17,000 to 25,000	42 to 61.5	19	30	12 to 31.5
10:39	7	1.5	6.5	407	17,000 " 25,000	42 " 61.5	19	30	12 " 31.5
11:0	6 and 4	1.5	6.5	420	16,000 " 22,000	38 " 52.5	18	30	8 " 22.5
11:4	6 and 8	1.5	6.0	420	17,000 " 27,000	40.5 " 54.0	22	30	10.5 " 34
						Average	19		20.2
				Test Run No. 4, Oct. 2, 1911					
12:43	6.5	1.08	5.5	445	17,500 to 19,500	39.6 to 44	5	21.6	17.9 to 22.4
1:24	6 and 4	2.44	12.	327	17,000 " 21,400	52 " 65.5	12	48.8	3.2 " 16.7
5:14	6	1.0	5.	752	18,000 " 20,500	24 " 27.3	7	20.0	4.0 " 7.3
5:22	6 and 7	.7	7.	373	7,000 " 9,500	18.8 " 25.5	15	14.0	4.8 " 11.5
5:37	7	1.5	13	373	13,500 " 15,500	36.2 " 41.5	7	30.0	6.2 " 11.5
6:0	6 and 7	.7	13.5	435	10,700 " 12,500	24.7 " 28.8	7.5	14.0	10.7 " 14.8
6:2	7	1.5	11.5	435	15,000 " 18,500	34.5 " 42.5	11	30.0	4.5 " 12.5
						Average	9.2		10.6
				Test Run No. 5, Oct. 3, 1911					
7:2	6	1.5	2.5	420	14,000 to 16,000	33.4 to 38.2	7	30.0	3.4 to 8.2
7:5									
7:6	4 and 8	1.5	3.	420	13,500 " 20,000	32.2 " 47.5	20	30.0	2.2 " 17.5
7:12									
7:18	7	1.55	6	258	8,500 " 15,000	33.0 " 58.2	27.5	31.0	2.0 " 27.2
7:22									
7:37	8	1.5	6.5	218	7,500 " 12,000	34.5 " 55.0	23	30.0	4.5 " 25.0
7:39	7	1.5	13.5	218	8,500 " 11,000	39.0 " 50.5	13	30.0	9.0 " 20.5
						Average	18.1		11.9
					Average on all reading		15.8		13.4

TABLE IV.—TONNAGE RECORD

TEST RUN NO. 1, SEPT. 23, 1911

From	To	Distance	Traling weight tons	Locomotive weight tons	Wattmeter reading kw-hr.	Kw-hr. freight	Kw-hr. swit hing	Ton-miles freight	Ton-miles locomotive	Ton-miles freigh switching	Ton-mile locomotive switching
Frazer	Niles	2.2 Mi.	151	41	74*	66		332.20	88		
		1000 ft.	15	41						2.8	7.8
		100 "	30	41						0.6	0.8
		750 "	430	41						61	5.8
		750 "	100	41						14.2	6
		200 "	85	41						3.2	1.6
		150 "	30	41						0.9	1.2
		250 "	15	41						0.7	2
		250 "	400	41						18.5	2
		1500 "	491	41	90		16			14.0	11.6
Niles	Hope	10 Mi.	491	41	218	128		4910.00	410		
		1005 ft.	464	41						87.8	7.8
		25 "	310	41						1.5	0.2
		590 "	177	41						19.8	4.6
		100 "	457	41						6.7	0.8
		590 "	136	41						15.7	4.6
		100 "	192	41						3.6	0.8
		50 "	12	41						0.1	0.4
		230 "	94	41						4.1	1.8
		77 "	215	41						3.1	0.6
		152 "	272	41	233		15			7.9	1.2
Hope	E. Ft. Dodge	20.3 Mi.	272	41	354.5	121.5		5,520	832		
		2570 ft.	272	41						132	19.9
		334 "	237	41						15	2.6
		210 "	334	41						13.30	1.6
		308 "	12	41						0.7	2.4
		460 "	29	41	364		9.5			2.5	3.5
E. Fort Dodge	Ft. Dodge	2.5 Mi.	29	41	370	6		72.5	102		
		Total				321.5	40.5	10,834.7	1432	429.7	91.6

Watt-hours per ton-mile: Freight 29.7; gross weight 20.2; freight switching 94.5; gross weight 77.8; all day service freight 32.2; gross weight 28.3.

*Wattmeter reading at start 8 kw-hr.

TABLE IV. (Continued).

TONNAGE RECORD

TEST RUN NO. 2, SEPT. 23, AND 26, 1911

From	To	Distance	Trailing weight tons	Locomotive weight tons	Wattmeter readings kw-hrs.	Kw-hrs. freight	Kw-hrs. switchings	Ton-miles freight	Ton-miles locomotive	Ton-miles freight switching	Ton-miles locomotive switching
E. Ft. Dodge	Rob. Hill	2.5	648	82	0			1,615	204		
Rob Hill	Rob. Side	1.2 Mi.	325	82				390	98.5		
Rob. Side	Rob. Hill	1.2 "	15	82				18	98.5		
Rob. Hill	Rob. Side	1.2 "	338	82				406	98.5		
Rob. Side	Roberts	1.3 "	648	82	98.4	196.8		843	106.5		
Roberts	Harcourt Switch	11.4 "	648	41	227	128.6		7,400	468		
		935 "	357	41						63.3	7.3
		470 "	15	41						1.3	3.7
		26 "	312	41	236		9			1.5	0.2
Harcourt Switch	Harcourt	1 Mi.	312	41	250	14		312	41		
		675 ft.	15	41						1.9	5.2
		155 "	46	41						1.3	1.2
		100 "	77	41						1.5	0.8
		990 "	170	41						32.3	7.8
		1015 "	455	41						99	8.9
		545 "	61	41						6.3	4.2
		25 "	452	41	260		10			2.1	0.2
Harcourt	Hope	3.9 Mi.	452	41	300	40		1,768	160.2		
Hope	Niles	10 "	450	41	404	104		4,500	410		
		935 ft.	155	41						27.5	7.3
		650 "	15	41	410		6			1.9	5.0
Niles	Boone Shops	9.7 Mi.	310	41	552	142		3,000	398		
		Total				625.4	25	20,252	2,083.2	239.9	51.8

Watt-hour per ton-mile: Freight 31.0; gross weight 28.0; freight switching 104; gross weight switching 85.5; all-day service freight 31.75; all-day service gross weight 28.8.

TABLE IV. (Continued.)
TONNAGE RECORD
TEST RUN No. 4, OCT. 2, 1911

From	To	Distance miles	Trailing weight tons	Locomotive weight tons	Kw-hr. wattmeter	Kw-hr. through freight	Kw-hr. switching	Ton-miles through freight	Ton-miles locomotive	Watt.-hr. per ton-mile net	Watt.-hr. per ton-mile gross
Switching			404	41	1134		44				
470	584	2.06	286	41	1178	80.0		590	84.5	135.5	119.0
Switching				41	1258		22				
601	1159	10.30	711	41	1280	178.0		7,330	423	24.3	22.9
1159	1347	3.60	711	41	1458	44.0		2,560	147	17.2	16.3
1347	2003	12.40	711	41	1502	132.0		8,830	509	15	14.2
2003	2134	2.18	711	41	1634	4.0		1,550	89.5	2.6	2.4
2134	2167	.66		41	1638	13.7		471	27.2	29.1	27.5
2167	2213	.68	332	41			30.7				
2173	2230	.91	332	41		31.7		302	37.3	105	93.5
2230	2164	1.08	0	41							
2164	2229	1.06	394	41	1754	39.9		418	43.5	95.5	86.5
		Total				523.3		22,051	1,361		

Watt-hour per ton-mile: 23.7: gross weight 22.3.

tances between trolley poles. Table IV gives the details of this movement, and the same data is summarized in a slightly different manner in Table V. In the latter table the schedule speed and the watt-hours per ton-mile in switching and freight service has been summarized for all the separate movements of Table IV. In obtaining the schedule speeds all time at stations in excess of five minutes has been deducted. There were a number of instances during the test where the train was held waiting for connections or train orders in excess of five minutes and all such cases time has been noted in a column by itself as "Time Lost." The "Time" noted in the column under "Switching" includes the time devoted to drilling cars and making up train, while the "Time" note in the column under "Main Line" includes all station stops not in excess of five minutes. The "Schedule Speed" is calculated from the corresponding time and distance. It is to be noted, however, that this schedule speed is reduced somewhat on account of time and distance lost in breaking trains and doubling on some of the heavy grades. This increases the distance actually traveled by the locomotive over that which would appear from the profile and the through mileage from one end of the run to the other. The increase in distance on this account is noted under the table.

TABLE V.
POWER CONSUMPTION

Test run	Total time-min.	Main Line				Time lost min.	Switching			
		Dist.	Time	Sched. speed	Watt-hr. per ton-mi.		Dist.	Time	Sched. speed	Watt-hr. per ton-mi.
No. 1	222.5	35	152	13.8	26.2	33	2.23	37.5	3.6	77.8
No. 2	343	43.4*	294	9.0	28.0	15	1.24	34	2.2	85.5
No. 4	285	34.9†	169	11.3	22.3	95		21		
Average				11.4	22.5				2.9	81.6

* Add 2.9 miles for doubling.
† Add 3.85 " " "

Power consumption as discussed in this section includes all the power used in the locomotive including that used for auxiliaries, lights, air-brakes, etc.

RATIO OF REVENUE FREIGHT TO GROSS WEIGHT

Table VI has been prepared showing for various portions of the test runs the total weight of the train and the proportion of this weight that represents car loading or revenue freight. In making up train weights only the gross weight of loaded cars was recorded, and in obtaining the net weight of freight, the weight of empty cars has been estimated in every case at 15 tons. Some slight error may be introduced by this fact as the average freight car probably weighs a little more than 30,000 lb. (13,607 kg.). On the other hand, the weight of train includes the weight of the 15-ton test car which would not be included in ordinary freight service and this would tend to offset any errors caused by assuming too low a weight for empty cars. The average results of the table probably indicate very fairly what may be considered the proportion of revenue freight in mixed service such as was investigated in these tests. The table covers runs aggregating 109 miles (175.4 km.) and shows that the revenue freight carried in the cars is approximately 50 per cent of the train weight.

TABLE VI

RATIO OF REVENUE FREIGHT TO TRAIN WEIGHT

Test	Dist.	Weight		Ton-miles		Ratio
		Total	Revenue	Total	Revenue	
	Miles	Tons				Per cent.
No. 1	2.2	192	80	422	176	42
	10.0	532	317	5,320	3,170	59.5
	20.3	313	158	6,350	3,210	50.5
No. 2	5.0	730	291	3,650	1,450	40
	11.4	689	291	7,850	3,320	42.3
	1.0	353	145	353	145	41.2
	3.9	493	145	1,930	565	29.4
	10.0	491	143	4,910	1,430	29.2
	9.7	351	143	3,400	1,390	41.0
No. 3	4.0	660	337	2,640	1,350	51.0
No. 4	2.06	327	184	673	380	56.5
	30.26	752	489	22,800	14,750	65
No. 5	3.5	420	247	1,470	865	59
Total.....	109.32			61,768	32,201	52

ACCELERATION

In order to obtain an idea of the rate of acceleration acceptable in practice an examination was made of the test records covering the starting of the train at various stops. Many of these records could not be used as the basis of accurate calculation on account

of lack of uniform current and other conditions caused by the slipping of drivers or other accidental occurrences. Ten of these starts have been selected in which the conditions were fairly uniform and the records plotted on a magnified scale. Of these Nos. 5, 6, and 7 are reproduced in Fig. 8. It should be noted in passing that the three accelerations shown in Fig. 8 correspond to the three starts shown in Figs. 6 and 7. The other acceleration curves have not been reproduced but the results of calculation of all of them are included in Table VII.

The following comments refer to this table:

Column 5 gives the rate of acceleration during the interval which is stated in column 4.

Column 6 expresses this acceleration in terms of pounds per ton.

Column 7 states the tractive effort for the total train due to acceleration alone.

Column 8 gives the total average tractive effort of the locomotive during the acceleration period, calculated from the tractive effort curves of the test record.

Column 9 under the heading " Friction Actual " is obtained by adding the figures in columns 7 and 3 and subtracting their sum from the corresponding figures in column 8; and shows the tractive effort available for train friction after making due allowance for that used for acceleration and grade resistance.

Column 10 gives the train friction reduced to pounds per ton. This train friction during acceleration exhibits wide variations. This might be expected from the fact that being derived from the other quantities all the uncertainties in acceleration, grade and current data are finally reflected in the train resistance. In addition to this there actually exist wide variations in the train conditions at starting due to variations in the condition of brake shoe application, cramping of trucks in track or against side bearings and other uncertain conditions which are largely eliminated after the train is running.

Column 11 gives the maximum value or surge of the tractive effort observed during the acceleration period.

Column 12 is derived from columns 8 and 11 and shows the ratio between the average tractive effort and the maximum surge. This ratio is largely dependent in any particular case upon the type of control used and the method of handling the controller by the engineer.

In discussing the results of this table it will be noted that

TABLE VII
ACCELERATION TEST

Curve No.	Tons train weight	Tractive effort due to grade	Acceleration				Tractive effort				
								Friction			
			Duration seconds	Miles per hour per second	Pounds per ton	Tractive effort	Average actual	Actual	lb. per ton	Max.	Ratio
1	445	0	26.0	0.173	16.6	7,400	16,500	9,100	2.04	24,300	0.68
2	327	0	16.6	0.349	33.6	11,000	12,200	1,200	3.67	17,300	0.71
3	752	0	30.0	0.133	12.8	10,000	17,420	7,420	9.87	20,300	0.86
4	752	—9024	20.0	0.143	13.8	10,300	12,625	11,350	15.10	15,500	0.82
5	373	+7460	20.8	0.144	13.8	5,160	21,400	8,780	23.50	25,000	0.86
6	373	+7460	23.5	0.225	21.7	8,090	17,400	1,850	4.96	23,500	0.77
7	435	+8700	29.0	0.127	12.2	5,320	17,400	3,380	7.78	20,000	0.87
8	660	0	42.0	0.171	16.5	10,900	9,860	?	?	12,500	0.79
9	258	+7740	26.0	0.115	11.0	2,850	16,400	5,810	22.50	19,700	0.83
10	218	+6540	28.0	0.193	18.5	4,400	14,520	3,940	18.10	17,100	0.85

although the results vary between rather large limits certain conclusions may be drawn as to the allowances and the assumptions which may be made in calculating upon acceleration of freight trains.

a. Allowance must be made for an increase in train resistance above the normal. Apparently a resistance of 15 lb. (6.8 kg.) per ton is fair for such conditions as are represented by the tests under discussion.

b. The allowable rate of acceleration may be as low as $\frac{1}{10}$ mi. per hr. per sec. or 10 lb. (4.5 kg.) per ton. This in combination with 15 lb. (6.8 kg.) per ton for train resistance is none too low as the train resistance falls off as soon as the train is under motion, giving a fair rate of acceleration over the range of the rheostat steps.

c. The available tractive effort for acceleration is not more than 80 per cent of the maximum tractive effort at the slipping point of the drivers. This means that if the slipping point is assumed at 30 per cent tractive coefficient, not more than 24 per cent tractive co-efficient is available for acceleration.

CONCLUSION

In conclusion the writer begs to repeat what was said earlier, that the results of this paper are not intended to replace any standard formulas on railroad train operation many of which have been carefully worked out and are supported by abundant experimental data. The paper is presented to show the results of actual tests in actual service and the amount of variation of those results from standard or average values.

The writer also wishes to acknowledge the courtesy of the officials of the Fort Dodge, Des Moines & Southern Railway Co., for extending their facilities to him; and to express his obligation to the students of the senior class in electrical engineering of the Iowa State Agricultural College who assisted in carrying out the tests and working up the results embodied in this paper.

A paper to be presented at the Boston Section Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 15, 1912.

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(*Subject to final revision for the Transactions.*)

NOTES ON UNDERGROUND CONDUITS AND CABLES

BY C. T. MOSMAN

The consideration of an underground conduit and cable system involves many points of interest besides that of the physical construction of the duct line, manholes, etc. The point of prime importance and interest is the load or current which may be safely carried through a duct, and this is intimately related to nearly every feature of construction of the duct system and of the cables.

The heat generated in the cables results principally from I^2R loss in the copper, but in the case of single-conductor cables carrying alternating currents may be considerably augmented by I^2R loss in lead sheathes, and slightly by dielectric hysteresis in the insulation.

The I^2R loss of large sizes of cable will be greater for alternating than for direct currents due to the effective increase in resistance resulting from skin effect. Cables of 1,000,000 cir. mils. or larger and for use on sixty cycle service should be provided with a hemp core, to reduce the skin effect to a negligible value.

This heat will be dissipated by conduction through the duct structure to the surrounding earth; by conduction along the copper lead to the manholes, and there dissipated by the ventilation, if any; by air currents through the ducts from manhole to manhole. There will be a continuous fall of temperature through the various mediums from the copper to the earth, so that additions must be made to any exterior temperature in order to arrive at the temperature of the copper.

The advisable limit of temperature of the copper differs according to the type of insulation used and the voltage impressed thereon. To avoid undue deterioration, rubber insulation should not be operated above 50 deg. cent. and varnished cambric or paper insulation above 80 deg. cent., and this latter figure should be understood to apply only to low potential operation.

The insulation resistance of insulating material varies with the temperature and differently for different insulations. The rate of decrease of insulation resistance with increase of temperature, of high quality rubber insulation is much lower than is the case with either paper or varnished cambric, the rate of decrease of paper being about four times that of good rubber, and the rate of varnished cambric about eight times.

The variation of resistance to puncture with variation of temperature is of much more importance than the variation of insulation resistance. The puncture resistance varies with the time of application of the potential. The instantaneous resistance to puncture of varnished cambric insulation is the same hot or cold, but above a critical temperature of 70 to 80 deg. cent. the sustained puncture resistance decreases with increase of temperature, while below 60 deg. cent. this effect is negligible. This effect seems to depend upon variations of dielectric hysteresis with temperature and it varies in percentage with the thickness of insulation.

This effect is not of practical moment in the case of cables built for operation at 2000 volts or less. With cable built for 2,500 volts the effect may be approximately 5 per cent with 10,000-volt cable about 20 per cent, and with 25,000-volt cable about 25 per cent.

It should be noted that the above stated decreases of puncture resistance exist only while the high temperature exists, the insulation regaining its normal resistance when cooled.

Paper insulation is subject to the same effect, but to a somewhat lesser degree.

Rubber insulation maintains its normal value of puncture resistance much better than either paper or varnished cambric. but suffers a permanent deterioration.

Consideration of the above indicates that it would be conservative to limit the copper temperature of high tension cable to 50 deg. cent. for any of the above types of insulation.

The thermal drop through the insulation will vary with the character and thickness of the insulation and the temperature of the copper, and the rate of dissipation of energy. Tests have been made on various types of insulation used on generator coils to determine the thermal drop. The results of tests by different experimenters differ widely.

One set of tests gives values of thermal drop in degrees centigrade per inch thickness of insulation per watt per square-inch dissipated of 169 for varnished cambric tape at the rate of 0.30 watts per sq. in., (6.45 sq. cm.) and 136 at the rate of 1.63 watts per sq. in. (6.45 sq. cm.) From these figures it would appear that at rates of radiation common in cable practice the thermal drop would be in excess of 169 deg. cent. per watt per square inch per one in. (2.54 cm.) thickness.

Applying the above to a varnished cambric insulated cable with a rate of 0.05 watts per sq. in. (6.45 sq. cm.) and insulation of 11/32 in. (8.7 mm.)thickness the copper may be expected to be at about 3 deg. cent. higher temperature than the surface of the cable, thus showing that this is not an important matter in connection with the average commercial cable. The drop in temperature through the air in a duct and along the length of the duct will depend upon the opportunity for a definite circulation of air through the duct, which will usually be negligible. The temperature drop through the duct structure will doubtless vary with the type of conduit, whether tile or fiber, and with the degree of dampness of the surroundings.

The position of the individual duct in the system will have great effect on its temperature elevation, the ducts next to earth at the bottom and sides being the coolest and those furthest removed from earth the warmest.

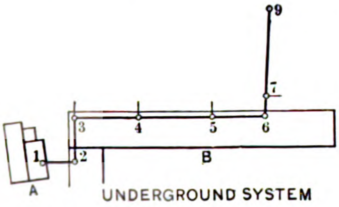

Fig. 1.

The foregoing must serve as my excuse for thinking that a reference to some actual tests made on a conduit system may prove of interest.

A manufacturing plant installed a conduit system in the mill yard using fiber conduit laid in cement. Because of physical limitations the 81 ducts were laid nine wide and nine deep. But few cables were at first installed but when later it became necessary to add to the number, it seemed wise to investigate somewhat before deciding upon the cable size and the permissible load per cable.

The main conduit line extends from manholes No. 1 to No. 9 as shown in Fig. 1.

Referring to Fig. 3, giving a section of the conduit line, it will be noted that all the cables installed are single conductor

1,000,000-cir. mil., paper insulated, except those in ducts 13, 14 and 15, which are 500,000-cir. mil. single conductor, rubber insulated.

Of the total length of main conduit line, the sections between manholes No. 1 and No. 2, and manholes No. 7 and No. 9, are the only sections which are actually underground. The balance between manholes No. 2 and No. 7, are above the basement floor level in one of the buildings; the lower row of ducts being some ten to twelve in. (25 to 30 cm.) above the floor level.

The latter sections being inside the mill basement, with three sides of the system exposed to air, may be expected to operate at higher temperatures than the former sections which are buried in moist earth. Further, these sections may be expected to always have a greater number of ducts occupied by loaded cables than sections 7 to 9. The limit of the capacity of the duct system hence should depend upon the hottest portion of these indoor sections. Thermometers were placed on the lead sheaths of the cables at the duct ends in manholes Nos. 7, 6, 5 and 4.

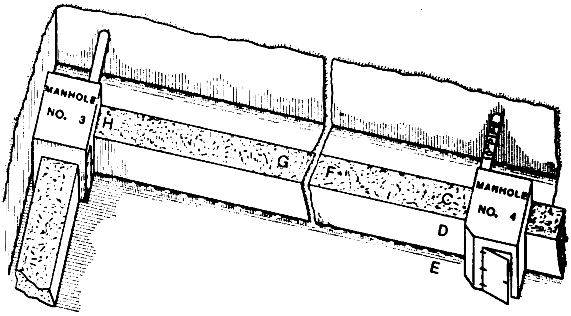

FIG. 2.—THERMOMETER LOCATIONS, CONDUIT LINE, MANHOLES 3 to 4.

A—Earth in manhole No. 4.
B—Air entering “ “ “ at vent pipe.
C—Top of duct line, as shown.
D—Side “ “ “ “ “
E—Earth near manhole, as shown.
F—Top of duct line, “ “
G— “ “ “ “ “ “
H— “ “ “ “ “ “

Devoting a day to each manhole, readings were taken hourly of temperatures and loads of the cables.

The results of these tests indicated that the highest temperature would be obtained at manhole No. 4, and the section from manholes No. 3 to No. 4 was finally taken as the one representing probably the severest condition as to temperature.

This section is located in the basement of a building where there are a number of steam and water pipes and where the temperature is usually rather high, as compared with actual under ground temperatures.

The section was tested under varying conditions of operation and ventilation. Thermometers were placed on the lead sheath of all cables carried through manhole No. 4 at the point where cables left the ducts on the power house side, and readings taken of the ampere load on each individual cable, together with the temperatures. The iron drawing-in wires in all the ducts not containing cables were connected to a 125-volt direct-current source that could be operated and controlled independently of the other apparatus, and readings taken of the current flow and drop across the conductors in each pair of ducts, from which was calculated the watts loss per foot and the average temperature of the iron conductor, a sample of the iron wire having previously been carefully tested and a temperature resistance curve obtained throughout a wide range of temperature, as shown in Fig. 4.

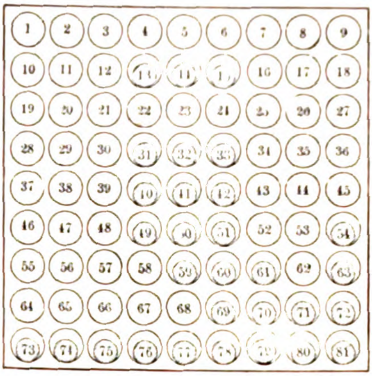

Fig. 3.—Section of Conduit Line, Manholes 3 to 4.

Ducts 13-14-15 contain 500,000 cir. mil rubber cables. Balance of ducts containing cables have 1,000,000-cir. mil paper cables installed.

All other ducts except 16-22-58 contain 0.049 galvanized iron wire, which was used as conductor during test.

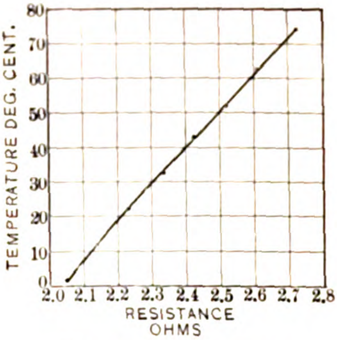

Fig. 4.—Resistance-Temperature Curve.

18 feet 0.049 galvanized iron wire.

It was the intention to obtain the temperature of the conductor by means of the drop of potential method and the temperature of the air in the duct by resistance test of the conductor with a wheatstone bridge after cutting current off the conductors and allowing them a sufficient time to reach the temperature of the air in the duct. The only available bridge at this time was of the slide wire type with telephones in place of galvanometer, and sufficient inductance from cables carrying load was obtained, so that this method had to be abandoned.

Fig. 2 shows roughly the appearance of the section tested and the location of the thermometers on the exterior of the duct line, while Fig. 3 shows a cross section of the duct line between manholes No. 3 and No. 4 looking toward manhole No. 3.

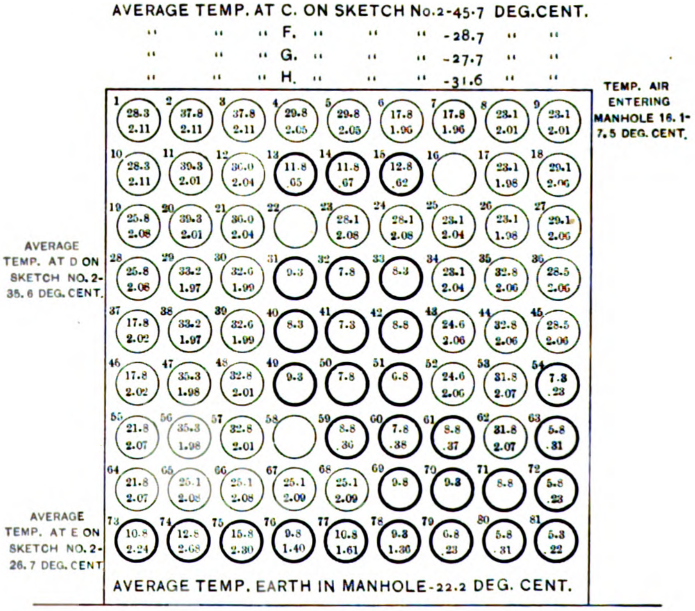

FIG. 5.—TEST No. 1, 11½-HOUR TEST, MANHOLE No. 4, NATURAL VENTILATION.

Heavy circles denote ducts containing cables.
Upper figures in circles are temperature rise in deg. cent. above earth in manhole.
Lower figures are watts loss per duct-foot, average for 11½ hr.
Small figures above circles are duct numbers.

TEST No. 1

This test was made with natural ventilation to the manholes through the pipes to outside wall, shown in Fig. 2. The current was applied to the iron test wires at approximately two watts per duct foot during the regular operating period of the mill, that is, from 6:30 a.m. to noon and from 1:00 to 6:00 p.m. The results of this test are shown in Figs. 5, 6 and 7.

Fig. 5 shows the average watts loss per duct foot and the temperature rise above the temperature of the earth in the manhole, plotted as a cross section of the conduit line. A study of the results indicated that considerable of the heat generated in the test wires must have been dissipated by the cables operating at low loads, as some of the temperatures near the center of the duct line were lower than some at the outside.

The maximum temperature rise was obtained in ducts No. 11 and No. 20, while the lowest maximum temperature rise in any duct containing test wire was obtained in ducts Nos. 6, 7, 37 and 46.

The low temperatures obtained on the cables is due primarily to the fact that the temperatures given are sheath temperatures at the edge of the duct, while those of the test wires are average temperatures of the conductor throughout its length, and an average of two ducts, combined with the fact that the air entering the manholes through the ventilating pipes blows directly across the cables just as they leave the ducts, and also to the light loads carried by the cables during the test.

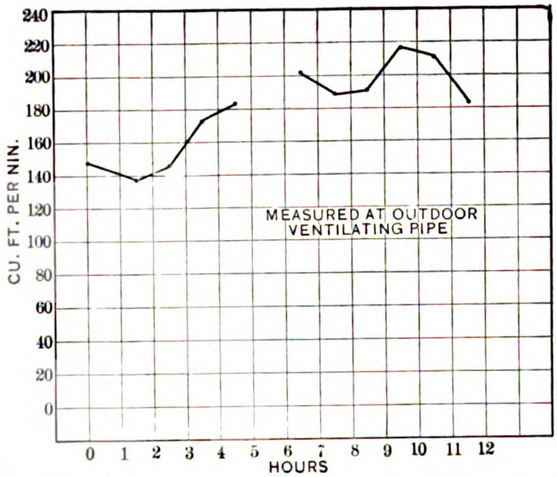

FIG. 6.—VENTILATION, MANHOLE NO. 4, TEST NO. 1.

During this test and all others on this section of the line there was a considerable draft of cold air blowing across the top of the conduit which came from the windows in the wall back of the conduit (See Fig. 2); the windows were not open and air blew in around the casings only. The test does not show, however, that this had any noticeable effect on the results obtained, except that there seems to be a tendency for the minimum temperature to be located slightly to the right of the centre.

TEST NO. 2

This test is a duplicate of the previous one, except that all outdoor ventilation to the manholes was stopped off and the manholes open for twelve hours before test was started and left open during test, so that the entire section of the conduit line might be of approximately the same temperature as the basement where it is located. This was done in an endeavor to approximate the conditions which it was assumed would be obtained in the summer months. It was found later, however, that summer conditions were not any more severe than in the winter, for the reason that windows in the wall back of the conduit line are then kept open and the temperature of the basement seldom exceeds the amount obtained during the winter months, so that Test No. 1 shows approximately the results which may be expected at any time of the year in this section of the conduit. The rise in temperature above that obtained in test No. 1 was not of any considerable amount. The whole cross section showed a slightly higher temperature and the temperature distribution was practically the same.

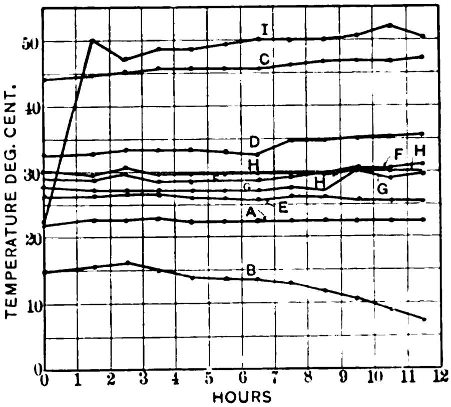

FIG. 7.—TEMPERATURES, SECTION FROM MANHOLE NO. 3 TO 4. NATURAL VENTILATION. TEST NO. 1.

A—Earth in manhole No 4.
B—Air entering " " " through ventilator—See Fig. 2.
C—Top duct line, see Fig. 2.
D—Side " " " " "
E—Earth near manhole, see Fig. 2.
F, *G*, *H*—Top duct line, " " "
I—Conductor (iron wire) center duct in top row.

TEST NO. 3

This test, except as to duration, is a duplicate of test No. 1. In this case the test was extended in order to approximate the results liable to be obtained if it became necessary to operate overtime. The results are shown in Figs. 8, 9, 10 and 11.

During the test the manholes were ventilated in the regular manner and the supply of air measured as shown in Fig. 9. In this particular case there was a strong draft of air through all vacant ducts, of which there were 57, from manhole No. 5 to No. 4.. This has been taken into account in plotting the results, so that the record gives the total amount of air supplied to manhole No. 4, with the exception of the quantity which came in from manhole No. 5 through the 24 ducts containing cables. It is doubtful if this condition will be found in practical operation as it seems extremely unlikely that the whole system would operate overtime on the same date.

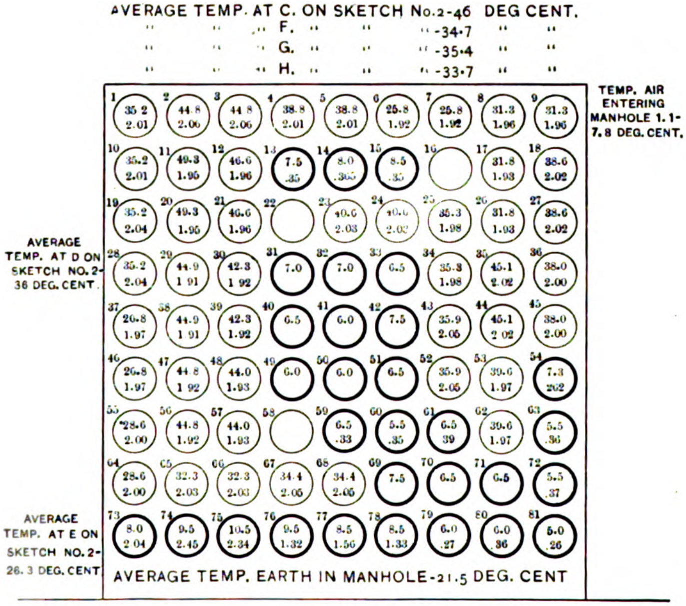

FIG. 8.—TEST NO. 3, 30-HOUR TEST, MANHOLE NO. 4, NATURAL VENTILATION.

Heavy circles denote ducts containing cables.
Upper figures in circles are temperature rise in deg. cent. above earth in manhole.
Lower figures are watts loss per duct-foot, average for 30 hr.
Small figures above circles are duct numbers.

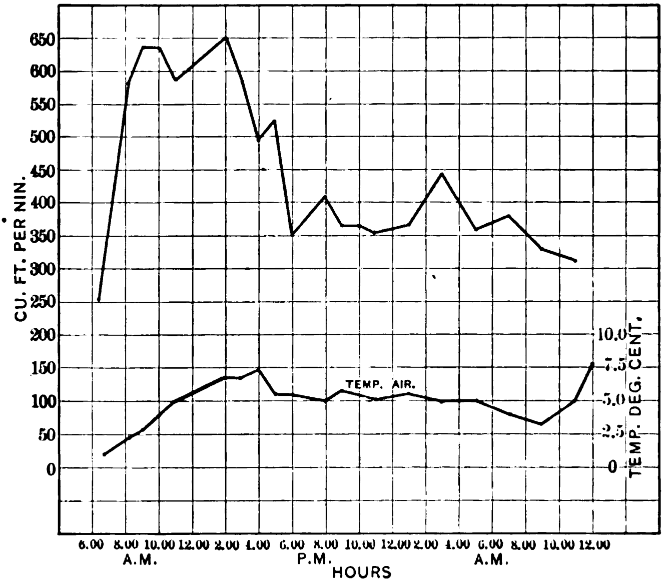

FIG. 9.—VENTILATION, MANHOLE NO. 4, TEST NO. 3.

Measured at ventilating pipe and also ducts to manhole No. 5—about equal quantities of air from each source.

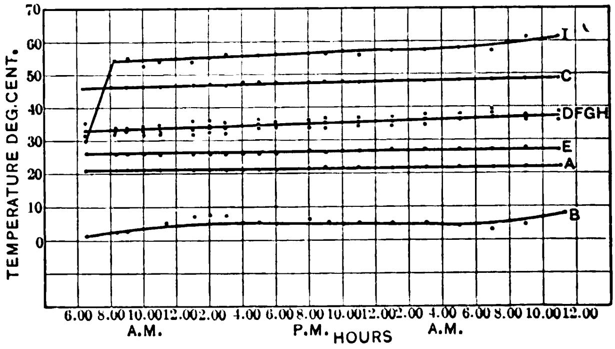

FIG. 10.—TEMPERATURES, SECTION FROM MANHOLE NO. 3 TO 4, NATURAL VENTILATION. TEST NO. 3.

A—Earth in manhole No. 4.
B—Air entering " " "
C—Top of duct line—see Fig. 2.
D—Side " " " " " "
E—Earth near manhole— " "
F, *G*, *H*—Top of duct line " "
I—Conductor, center duct, top row.

The tests so far described show only average temperatures and give little basis for determining the temperature at the middle point of a duct or throughout its length. To investigate this distribution a number of copper resistance coils were made up and inserted in various ducts. The coils were of circular cross section, wound with fine copper magnet wire upon a wooden mandrel and enclosed in a sheet copper envelope, after which they were dried and thoroughly impregnated with paraffin in such a way that the containing envelope was entirely filled. This was done with the intent to render the coils waterproof, and to reduce the thermal resistance so that rapid tests could be made. Each coil was supplied with four leads, two of which were soldered directly to the winding, the other two being merely soldered together inside the coil casing and used to determine the resistance of the coil leads so that the resistance of leads might be deducted from coil resistance measurements. All resistance measurements were made by a portable decade set. A temperature resistance curve of each test coil was made, and used as a basis for temperature determinations of ducts.

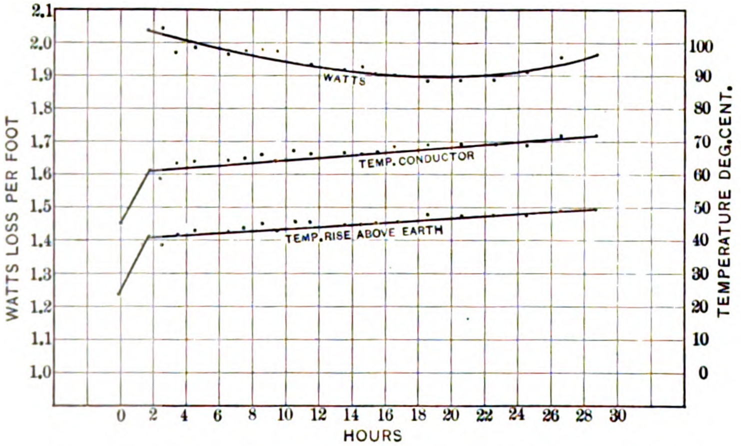

FIG. 11.—TEMPERATURE, DUCTS 11 AND 20, TEST NO. 3.

Before making test for temperature distribution in the length of ducts, it was decided to place the test coils midway between manholes No. 3 and No. 4 and determine what, if any, temperature variation there was in the cross section of the conduit system due to the normal loads on the cables installed, no load on iron wires. This was done and the following Table 1 gives the results obtained:

TABLE I

Time	Temperatures, deg. cent.				Duct Nos.					
	2	5	20	35	3	45	56	62	68	74
9.00	22.3	21.5	22.7	22.7	22.4	21.5	21.3	23.6		30.8
10.00	22.7	21.7	23.0	22.7	22.4	21.5	23.1	23.8		31.4
11.00	22.7	21.7	23.0	22.9	22.4	21.9	23.1	23.8	26.3	32.1
12.00	22.7	21.7	22.7	22.9	22.2	21.9	23.1	24.0	26.4	32.4
1.00	22.0	20.6	22.3	22.3	21.3	21.1	22.9	24.0	26.4	29.0
2.00	22.3	21.2	22.5	22.3	22.2	21.5	23.1	24.3	26.7	31.1
3.00	22.3	21.7	22.7	22.5	22.2	21.9	23.6	24.3	27.0	32.2
4.00	22.3	21.7	22.7	22.5	22.2	21.9	23.6	24.3	27.0	32.2
5.00	22.3	21.7	22.7	22.5	22.2	21.9	23.6	24.5	27.9	33.4

One coil was placed in duct No. 2 (refer to Fig. 3) which is exposed to the air on one side and surrounded by vacant ducts on the other three sides; this shows practically no temperature variation.

Four coils were placed, one in each of the ducts Nos. 20, 35, 38 and 56, which were surrounded on all sides by vacant ducts; except for No. 56 these show little temperature variation except for a slight cooling due to the noon shutdown.

A coil was placed in duct No. 5 which is exposed on one side to the air, on the opposite side to a duct containing a cable, and on the other two sides to vacant ducts; this shows practically no variation except at noon, and was at a generally lower temperature than those mentioned above, probably due to the proximity of cables operating at very light loads. The lead sheaths of these cables presumably conducted heat to the ends of the ducts and dissipated it to the air in the manholes.

A coil was placed in duct No. 45, which is situated quite similarly to No. 5, the adjacent cable carrying a very light load.

Two coils were placed one in each of ducts Nos. 62 and 68 which were surrounded on all but one side by ducts containing cables carrying loads, on the remaining side there being a vacant duct; these show a higher temperature and slightly more variation.

One coil was placed in duct No. 74 which contains a cable carrying an average load of 410 amperes; this shows a higher temperature than any of the others, as should be expected, and by comparing with the temperatures by thermometer of the lead sheath at the manhole it was seen that at the middle point of the duct the temperature is 18 per cent higher with 20 per cent less current in the cable.

Duct No. 56 though surrounded by vacant ducts shows a higher temperature than ducts Nos. 20, 35, and 38 similarly situated; this is probably due to the heat from ducts Nos. 73, 74, and 75 rising through the duct structure.

The temperatures shown by this test are low and the variations negligible due to the small loads carried by most of the cables at the time and the large number of vacant ducts.

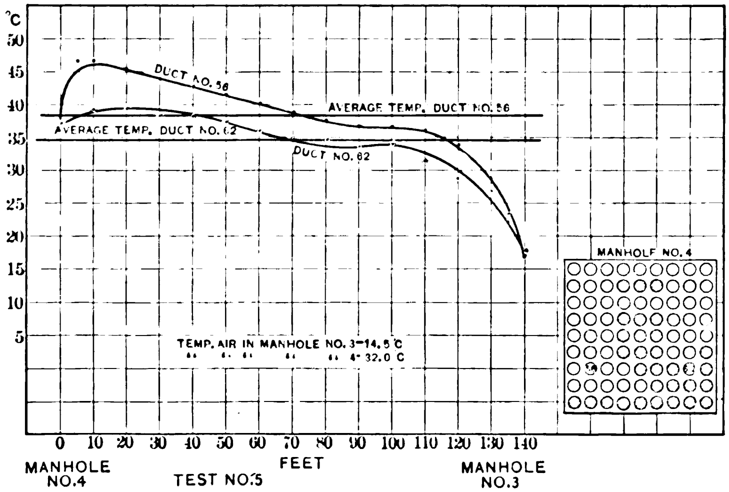

FIG. 12.—TEMPERATURE—LENGTH. MANHOLES 3 TO 4.

Ducts Nos. 56 and 62. After 24 hours continuous operation at 2 watts per foot loss. Velocity of air 2.5 ft. per second, natural ventilation. Ducts 3 in. diameter. 8.8 cu. ft. of air per minute.

Worked from center to manhole No. 3, then from center to manhole No. 4, the temperature essentially constant during the test.

TEST NO. 5

In order to determine the resulting effect of an air circulation through the ducts containing test wires, all openings to basement in manhole No. 3 were closed, as well as all openings to outdoor air in manhole No. 4, so that a measurable circulation of air from manholes No. 3 to No. 4 through ducts containing test wires could be obtained. The test wires were operated at two watts per duct foot for 24 hours before taking readings.

The distribution of temperature throughout a duct was obtained by resistance readings on a test coil at various positions in the duct, with constant load on the iron wire.

The distribution of temperature in ducts 56 and 62 is shown in Fig. 12. This figure clearly brings out the advisability of surrounding a heavily loaded cable with others carrying light loads, as the conductor in duct No. 62 surrounded on three sides by cables operated at a lower temperature than that in duct No. 56 surrounded by conductors carrying equal loads.

It is to be noted that the maximum temperature in duct No. 62 is 13 per cent greater than the average, while the maximum in duct No. 56 is 21.4 per cent greater than the average. It is therefore, reasonable to assume that the temperatures obtained in tests Nos. 1, 2 and 3 should be increased approximately 15 per cent to obtain the approximate maximums, as the values given were obtained by calculation from the drop across a test wire which must necessarily give average values.

TEST NO. 6

It was found in the previous test that the maximum temperatures occurred at approximately 15 ft. (4.5 m.) from manhole No. 4 when using natural drift. On that account all of the test coils were located at that position in this test. Previous to the commencement of this test the ducts containing test wires were operated at two watts loss per foot for 48 hours, while the ducts containing cables operated at their usual loads. The temperatures attained by the air in the ducts 15 ft. (4.5 m.) from manhole No. 4 are shown in the following Table No. 2.

While not entirely consistent, yet a comparison of this table with duct locations shown in Fig. 3 shows the influence of lightly loaded cables in adjacent ducts. A comparison with Fig. 12 shows that in 24 hours the ducts arrive at practically a constant temperature with natural ventilation when loaded to two watts per duct foot by the iron wires.

TABLE II

Duct. No.	Temperature 15 ft. (4.5 m.) from Manhole No. 4
2	41.5 deg. cent.
5	45.0 " "
20	52.5 " "
35	51.5 " "
38	51.5 " "
45	42.5 " "
56	50.0 " "
62	41.0 " "
68	45.5 " "

At 8:30 a.m. forced draft was applied, the input to blower motor being 2.2 kw., and readings taken until 10:30 a.m. The results

are sufficiently indicated by Fig. 13. It was noted that at the completion of the test the average temperature of all ducts was approximately 25 deg. cent., and the temperature rise above incoming air 20 deg. cent. This indicates the feasibility of operating the system at greater loads by the application of forced draft. It does not, however, give any indication of what air pressure would be required, as in this test the large combined area of the vacant ducts was equivalent to the blower exhausting to the free atmosphere. Possibly less volume of air would be required to carry off the same heat if the ducts contained cables, because of the large area of cable sheath surface to come in contact with the air.

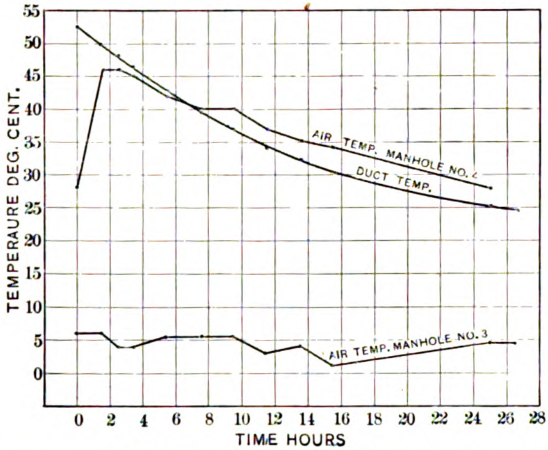

FIG. 13.—TEMPERATURE VARIATION WITH FORCED DRAFT, DUCT NO. 20. TEST NO. 6.

After 48 hours operation at 2 watts loss per foot, 475 cu. ft. air per minute at a velocity of 13.8 ft. per second. Duct temp. taken by resistance coil in duct 15 ft. from manhole No. 4.

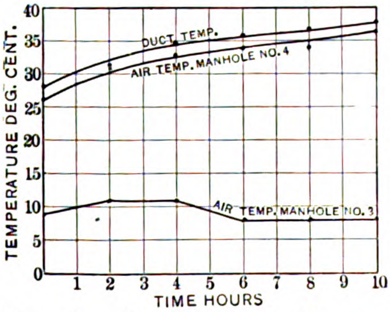

FIG. 14.—TEMPERATURE VARIATION WITH FORCED DRAUGHT, DUCT NO. 35.

At 4 watts loss per foot, and 500 cu. ft. of air per minute. Duct temperature obtained with resistance coil in duct 15 ft. from manhole No. 4. Test No. 7.

TEST NO. 7

As soon as test No. 6 was completed the forced draft was shut off and connections on test wires changed so that four watts loss per foot could be obtained and test No. 7 started at 11:30 a.m., running to 9:30 p.m. The results are sufficiently indicated by Fig. 14. The maximum temperature rise above incoming air in no case exceeded 30 deg. cent. under these conditions. It, therefore, seems that taking into account the relief afforded by noon shutdown the system may be operated at four watts loss per foot of duct, provided it is possible to force a sufficient amount of air through ducts containing cables. Unfortunately no test was made to determine the air required to cool a duct containing a cable, or the pressure necessary to force that air through, as might have been done by plugging up all vacant ducts and measuring the air delivered from manhole No. 4.

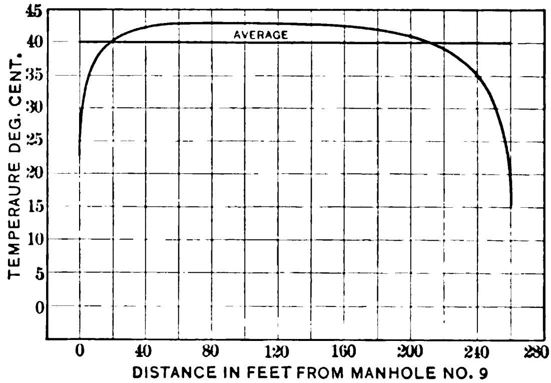

FIG. 15.—TEMPERATURE VARIATION, CENTER DUCT, BETWEEN MANHOLES NO. 7 AND 9, TEST NO. 9.

After 24 hours operation of all ducts containing wires of 2 watts loss per foot. This duct contained no wire or cable.

Temperatures in deg. cent.

Manhole No. 7		Manhole No. 9	
Earth temp., top	— 17.4	Earth temp., top	— 17.4
" " bottom	— 16.3	" " bottom	— 16.3
Av. manhole temp.	— 15.1	Av. manhole temp.	— 16.8

Average temp. for line—16.0

TEST NO. 9

Every test on the section of conduit line from manhole No. 3 to No. 4 brought to light more clearly the fact that no accurate deductions as to temperature conditions could be made from the tests on account of the dissipation of the heat produced by the test wires through the cables operating at light loads. On that account arrangements were made to have further tests on the section of conduit line from manhole No. 7 to No. 9, which contained but six cables located in the lower right hand corner of the line when viewed from manhole No. 9, *i.e.*, ducts 70, 71, 72, 79, 80 and 81, Fig. 3. The main conduit line ends at this manhole and only a short length of duct exists between the opposite side of the manhole and the outdoor air where the cables are suspended from the underside of a bridge structure. During the tests in this section all ducts leading to the outdoor air were tightly closed to eliminate any air circulation that existed.

The iron drawing-in wires were used for heating in this section as in the previous tests, and the connections were so made that all ducts except the center one and the six containing cables were heated.

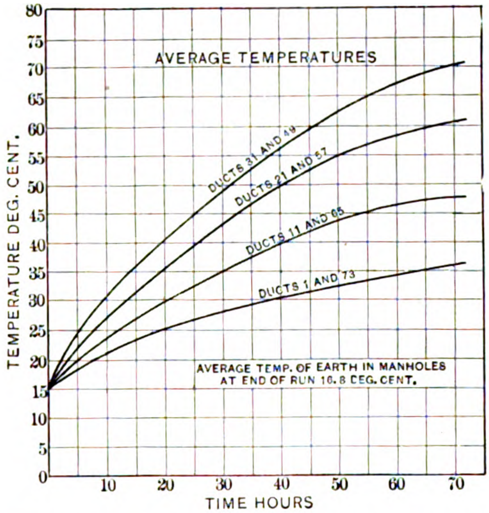

FIG. 16.—TEMPERATURE VARIATION IN CROSS SECTION OF CONDUIT LINE DURING CONTINUOUS RUN OF 72 HOURS.

At 2 watts loss per foot. Manholes 7 to 9. Test No. 10.

The first test consisted of measurement of the temperature throughout the length of the centre duct with a resistance coil to determine the point of highest temperature. The results are shown in Fig. 15. It is to be noted that the temperature at manhole No. 9 is five degrees higher than at No. 7. This is believed to be due to the presence of the test connections and the operator at No. 9, but principally to the general tendency of the draft to be from No. 7 to No. 9.

This figure again shows the advantage of resistance coil test of temperature over the drop of potential in the iron conductor method, as the maximum temperature is 6 per cent in excess of the average.

It was expected that this test would establish an approximate rule for the per cent to increase the values obtained in section between manholes No. 3 and No. 4, which were made by the drop of potential method, in the iron wires but as this shows only 6 per cent increase while previous tests on the previously mentioned section indicated an increase of from 13 to 21 per cent, it was concluded that undoubtedly the larger values were more nearly correct for that section, as the temperature of the exterior of concrete envelope in the basement must of necessity be higher than when under ground.

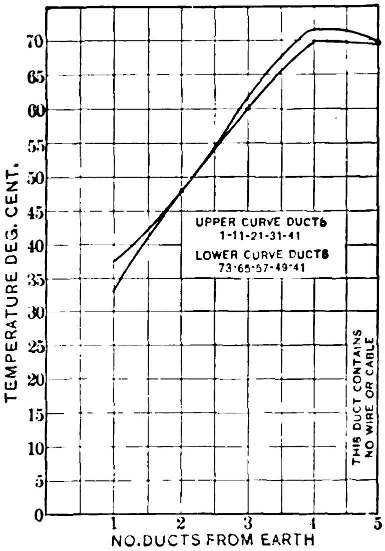

FIG. 17.—TEMPERATURE VARIATION IN CROSS SECTION OF DUCT LINE, MANHOLES 7 TO 9.

After 72 hours continuous operation at 2 watts loss per foot. Test No. 10.

TEST No. 10

In order to get this section of the conduit line into a condition approximately equal to what would be obtained during the summer months with the line full of cables, current was maintained at two watts loss per duct foot on the iron wires continuously for 72 hours, during which time readings were taken on the resistance coils which were located approximately midway between the two manholes. Figs. 16 and 17 have been plotted from the results.

In Fig. 16 the average of the temperatures of two ducts similarly situated is plotted.

Fig. 17 shows the temperature variations in the cross section of the conduit. It is to be noted that there is little difference between the two curves.

TEST NO. 11

After the completion of the previous test the current was cut off from the iron wires and the conduit line allowed to cool off for 48 hours, when current was again applied and maintained for one week at two watts loss per foot in exactly the same manner as would be the case if this section were carrying the regular mill load with each duct containing a cable. The results are shown in Figs. 18, 19, 20 and 21, which show the maximum temperature is not reached until the evening of the fifth day. At that time the average temperature of the earth was 17.5 deg. cent., so that temperature rise of the hottest duct was 49 deg. cent.

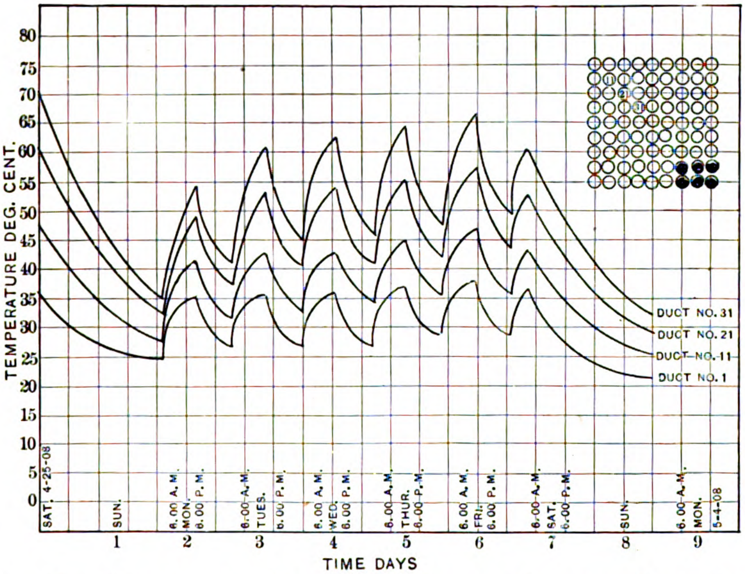

FIG. 18.—TEMPERATURE VARIATION, NORMAL RUNNING CONDITION, FOR ONE WEEK.

At 2 watts loss per foot. Between manholes 7 and 9, Test No. 11.

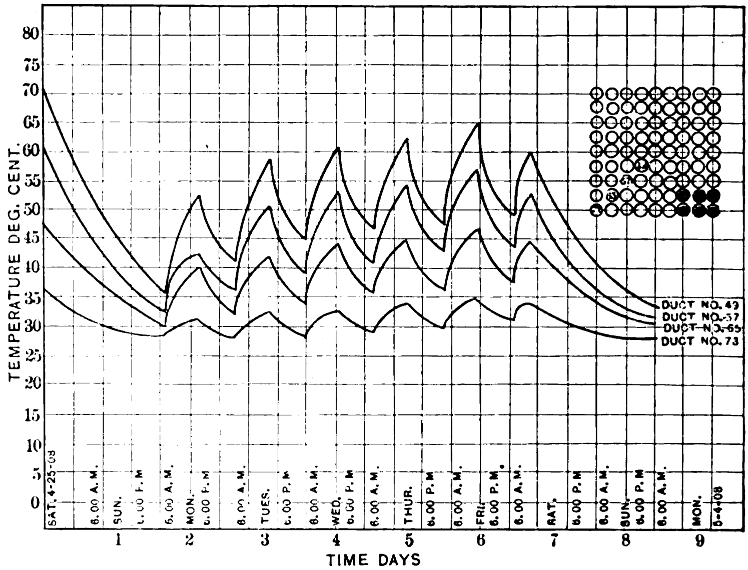

FIG. 19.—TEMPERATURE VARIATION, NORMAL RUNNING CONDITION, FOR ONE WEEK.

At 2 watts loss per foot. Between manholes 7 and 9, Test No. 11.

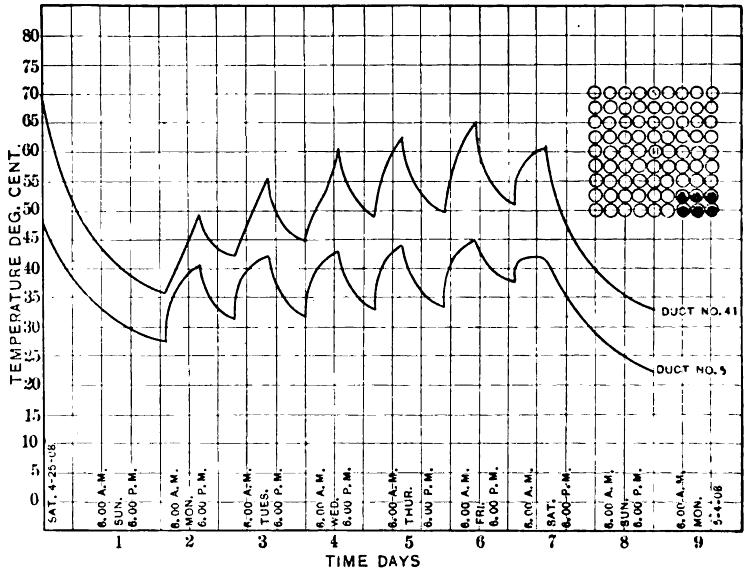

FIG. 20.—TEMPERATURE VARIATION, NORMAL RUNNING CONDITION, FOR ONE WEEK.

At 2 watts loss per foot. Between manholes 7 and 9, Test No. 11.

Test No. 12

The preliminary tests showed that the cable in duct 76 was four degrees warmer than the one in duct 74 with 27½ per cent less load. This, in view of the fact that all the cables were bonded together in manhole No. 3, indicated that undoubtedly the removal of the bonds would result in increased carrying capacity for the same temperature. In order to determine the probable values of sheath currents, tests were made both on cables already installed and on cables especially arranged for that purpose.

Two short lengths of 1,000,000-cir. mil. cable were placed in short lengths of conduit and connected as shown in Fig. 22, cable *A* being 13/64 in. (5.15 mm.) rubber and 3/32 in. (2.38 mm.) lead, over all diameter 1.738 in. (34 mm.) and cable *B* being 4/32 in. (3.17 mm.) paper and 4/32 in. (3.17 mm.) lead, over-all diameter 1.645 in. (31.8 mm.) Thermometers were placed on the copper core by means of a hole drilled through both the sheath and insulation. The hole was made somewhat larger than the thermometer bulb and all vacant space tightly packed with asbestos fiber. This method of getting the copper temperature is somewhat crude, but as no instruments suitable for other methods were available, it was used.

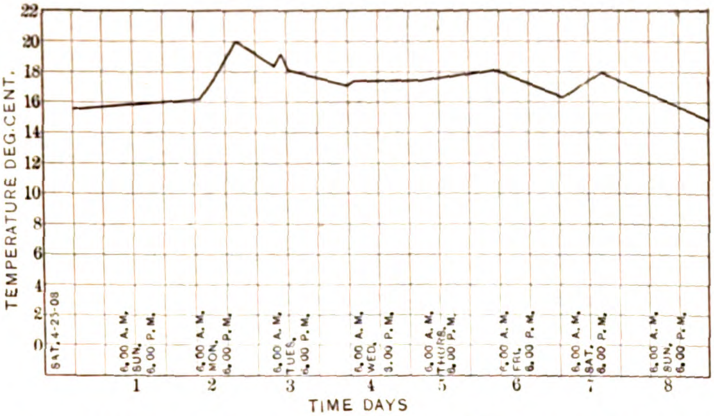

Fig. 21.—Average Temperature, Earth, Manholes 7 and 9, Test No. 11.

Thermometers were also placed on the sheath of the cables and the outside surface of the conduit. The temperature of the air in the duct was obtained by means of resistance coils suspended inside, out of contact with either conduit or cable.

The sheath currents obtained are shown in Figs. 23 and 24.

Curve 1 of Fig. 23 gives the actual values of sheath current obtained on the test of the short lengths of cables, and Curve 3 gives the calculated value upon deducting the resistance of the ammeter and bond contacts measured by a bridge, while curve 4 gives the value which would have been obtained with negligible bond and ammeter resistance and both cables having the same cross section of lead as the paper insulated cable.

Curve 2 is the average of several tests made on the sheathes of cables in No. 1 and No. 2 spinning circuits. These cables are solder bonded in manhole No. 3 approximately 275 ft. (83.8 m.) from the power house, where readings were taken by means of an ammeter and clamped bonds. Undoubtedly this curve gives the most reliable information, as it was made up from the tests of actual working conditions.

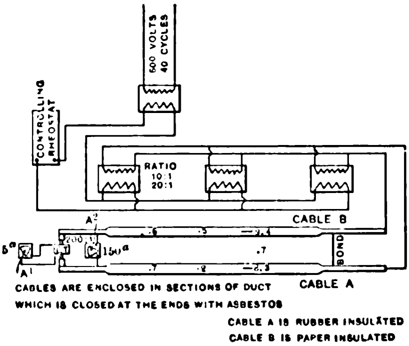
600 VOLTS
40 CYCLES
CONTROLLING RHEOSTAT
RATIO
10:1
20:1
CABLE B
A2
200
150a
5a
A1
.6
.5
.4
.7
.7
.8
.3
BOND
CABLE A
CABLES ARE ENCLOSED IN SECTIONS OF DUCT WHICH IS CLOSED AT THE ENDS WITH ASBESTOS
CABLE A IS RUBBER INSULATED
CABLE B IS PAPER INSULATED

FIG. 22.—DIAGRAM OF CONNECTIONS IN TEST OF VARIATION IN TEMPERATURE AND BONDING OF 1,000,000-CIR.MIL CABLES.

Thermometers:—1-lead sheath, cable *A*; 2-copper, cable *A*; 3-lead sheath, cable *A* 4-lead sheath, cable *B*; 5-copper, cable *B*; 6-lead sheath, cable *B*; 7-air; 8-outside of duct, cable *A*; 9-outside of duct, cable *B*.

Fig. 24 shows the watts loss per foot of conductor in both sheathe and copper, as well as combined loss. In making up this curve the values of sheathe loss were calculated from current values shown in curve 2 of Fig. 23, using a resistance per foot of lead sheathe of 0.000182 ohms at 20 deg. cent. These curves illustrate the necessity of keeping the lead sheathes of single conductor cable carrying large alternating currents from contact.

Figs. 25, 26, 27 and 28 show the temperature results of the tests on the experimental cables, Figs. 25 and 26 on the paper cable, and Fig. 27 and 28 on the rubber.

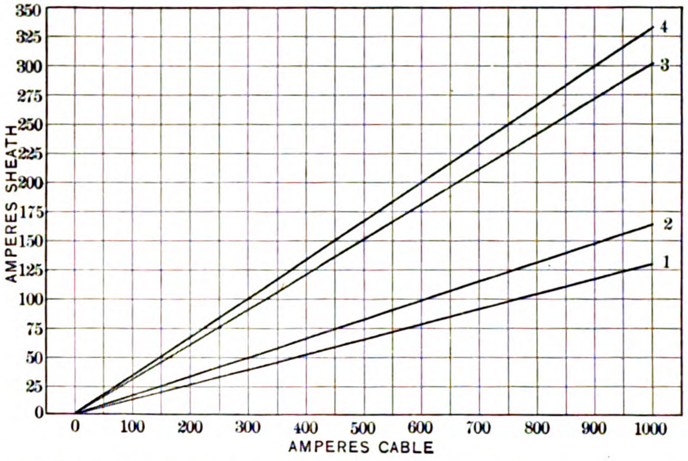

FIG. 23.—SHEATH CURRENTS IN BONDED CABLES—TEST NO. 13.

1—Test on 17 ft. 1,000,000 cir. mil cable.
2—Test on Nos. 1 and 2 spinning circuits.
3—No. 1 corrected for bond resistance.
4—No. 3 corrected to basis of sheath of paper cable.

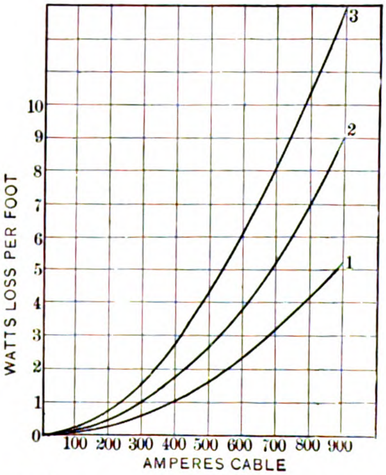

FIG. 24.—WATTS LOSS PER FOOT, 1,000,000–CIR. MIL CABLES.

1—Sheath loss.
2—Copper loss.
3—Combined loss.

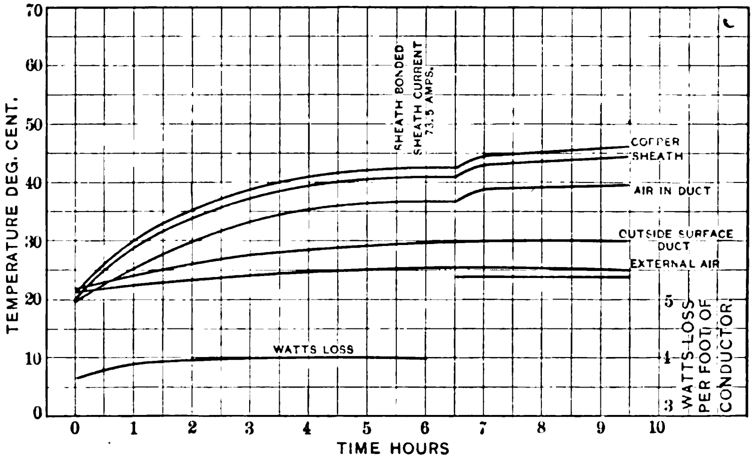

FIG. 25.—TEMPERATURE OF 1,000,000-CIR. MIL CABLE.
4/32 in. paper, 4/32 in. lead. In conduit, at 600 amperes. Test No. 12.

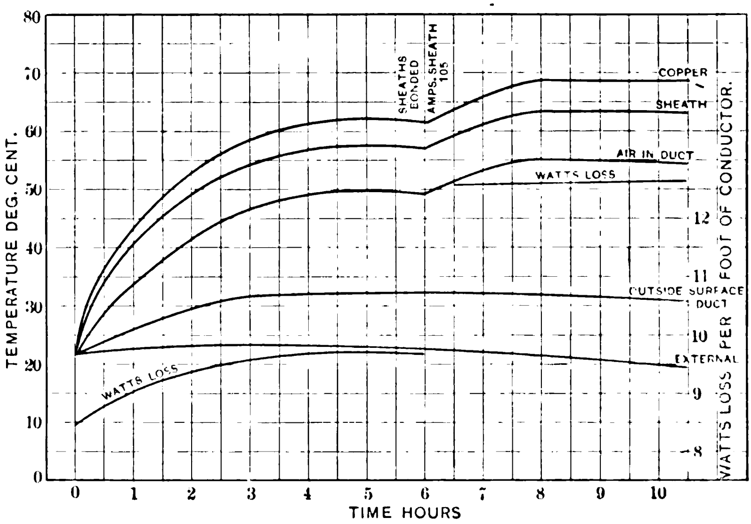

FIG. 26.—TEMPERATURE OF 1,000,000-CIR. MIL CABLE.
4/32 in. paper, 4/32 in. lead. In conduit, at 900 amperes. Test No. 12.

These curves are principally of interest in showing the distribution of the thermal drop through the various insulating mediums from the copper to the outside air.

Due to the thinness of the insulation adjacent to the copper the thermal drop therein is small, but it agrees fairly with more careful determinations made on various kinds of insulation on coils.

Due to the tests detailed in this paper being almost entirely based on heat generated in iron wires and in ducts containing only the iron wire, and hence having very different radiating and ventilating characteristics from ducts containing commercial cables, it is difficult to establish therefrom a limit to the safe loading capacity of the ducts. However, taking into account the fact that the sheath of a cable will transmit considerable heat to the duct end and thereby more or less offset the better ventilation of a duct containing only an iron wire, and that the curves show practically constant temperature in the duct with only iron wires, except near the ends and the low temperatures shown by the tests, and allowing for the cooling effect of the noon and night shut-downs, it seems safe to conclude that any portion of the conduit line may be safely operated at about 2.5 watts loss per foot of duct with natural ventilation and at about 4 watts loss per foot with sufficient forced ventilation, provided all light loaded cables are located at the center of the conduit with the heaviest loaded cables in the outside ducts.

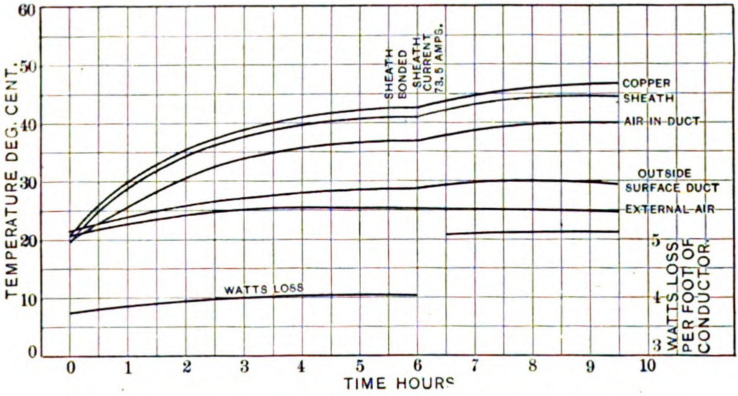

FIG. 27.—TEMPERATURE OF 1,000,000-CIR. MIL CABLE.
13/64 in. rubber, 3/32 in. lead. In conduit, at 600 amperes. Test No. 12.

Cables heavily loaded should not be placed in the top ducts, as there is a natural tendency for the rising heat of the entire system to elevate the temperature of these ducts above the rest.

By referring to Fig. 24 it will be found that 2.5 watts loss per foot corresponds to about 475 amperes load on the 1,000,000 cir.mil. cables and four watts loss per foot to about 600 amperes.

In order to operate the line at these values of loss, it is not only necessary to properly locate the cables with regard to their loads, but also to arrange the cables so that there is little or no possibility of their coming in contact in the manholes. An accidental contact between the lead sheathes will result in puncture of the sheathes if they are bonded or in contact with each other at some other point.

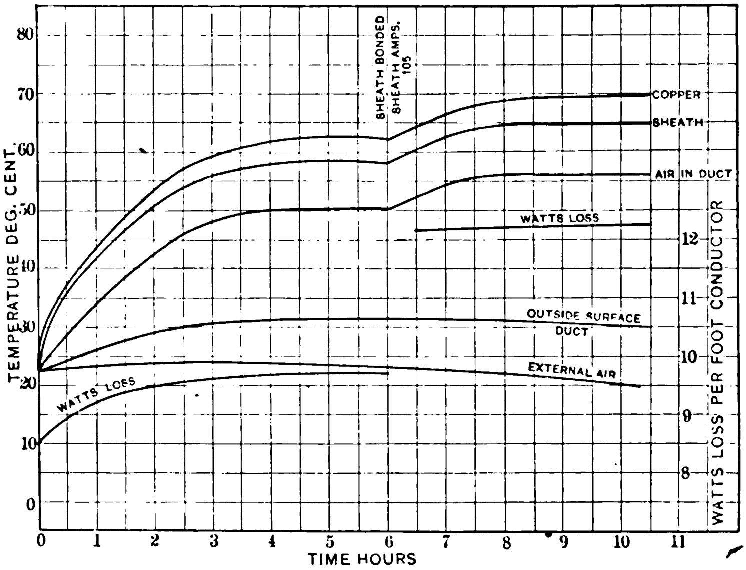

FIG. 28.—TEMPERATURE OF 1,000,000-CIR. MIL CABLE.
13/64 in. rubber, 3/32 in. lead. In conduit, at 900 amperes. Test No. 12.

The passage of the alternating current through the conductor induces an e.m.f. in the cable sheath and unless the sheathes are grounded the sheathe of a long length of cable may be at a moderate potential above earth. Possibly the wisest procedure would be to bond together all cables of the same phase at one point and ground them there through a resistance.

Where single-conductor lead covered cables carrying alternating current are supported in manholes on iron brackets, the sheathes may be insulated from the bracket by split rubber lined hose.

During heavy short circuits in the system, however, the cables carrying the short-circuit current may be thrown from their supports by the magnetic repulsion or attraction due to large currents. This forms a strong argument in favor of wrapping all cables in manholes with asbestos tape, afterwards treated with silicate of soda, and the use of fibre duct, thus insulating against the sheath voltages.

The lead sheathes of cables carrying high potential currents should always be grounded at some one point.

PROCEEDINGS

of the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

SECTION II

Papers, Discussions and Reports

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A paper presented at the Schenectady Meeting of the American Institute of Electrical Engineers, Schenectady, N. Y., May 17, 1912.

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(*Subject to final revision for the Transactions.*)

FREQUENCY

BY D. B. RUSHMORE

The subject of frequency for commercial power and lighting systems, far from being settled, is discussed again with every new installation. Frequency affects the operating characteristics of circuits and apparatus, and also their cost.

The frequencies in commercial use in this country are shown in the upper part of the accompanying table. While 40 cycles might possibly have been the best frequency for general use, it did not become standard, and the choice is now between 25 and 60 cycles. The uncertainties regarding future developments in large railway work have to be given some consideration. The physiological effect of different frequencies has been shown to be a matter of much importance and it is being investigated. Of the effect of different frequencies of light rays on vegetable life but little is yet known.

In the following discussion the influence of frequency will be treated in connection with generators, transformers, transmission lines, lightning, induction motors, synchronous motors, frequency changers, synchronous converters, railroad work, switching phenomena and illumination.

GENERATORS

A general formula for the induced e.m.f. of all generators is as follows:

$$E_1 = 4\, k_w\, k_f\, f\, n\, \phi\, 10^{-8}$$

The frequency of synchronous machines in alternations per minute is equal to the number of poles times the revolutions per

FREQUENCY

	Cycles	Wave length
Alternating current field	15	20,000 km. = 12,500 mi.
	25	12,000 km. = 7,500 mi.
	30	10,000 km. = 6,200 mi.
	33	9,100 km. = 5,650 mi.
	40	7,500 km. = 4,650 mi.
	50	6,000 km. = 3,750 mi.
	60	5,000 km. = 3,100 mi.
	66	4,550 km. = 2,800 mi.
	125	2,400 km. = 1,500 mi.
	133	2,250 km. = 1,400 mi.
Sound—Lowest audible	15	66 ft. in air
Highest audible	8,000	1.5 in. in air
High-frequency currents, surges, oscillations, arcing grounds, lightning, etc.		
Wireless telegraph waves	10^5	3 km. = 10,000 ft.
	10^7	30 m. = 100 ft.
Hertzian waves	10^7	30 m. = 100 ft.
	10^9	30 cm. = 1 ft.
Limit of electric waves	5×10^{10}	0.6 cm. = 0.25 in.
Visible light rays:		
Ultra red	3.7×10^{14}	81×10^{-6} cm.
Red	4.61×10^{14}	65×10^{-6} cm.
Orange	5.15×10^{14}	58.3×10^{-6} cm.
Yellow	5.44×10^{14}	55.1×10^{-6} cm.
Green	5.86×10^{14}	51.2×10^{-6} cm.
Blue	6.32×10^{14}	47.5×10^{-6} cm.
Indigo	6.66×10^{14}	44.9×10^{-6} cm.
Violet	7.5×10^{14}	40×10^{-6} cm.
Ultra violet rays	7.7×10^{14}	39×10^{-6} cm.
	30×10^{14}	10×10^{-6} cm.
X-rays (estimated)	3×10^{18}	0.1×10^{-6} cm.

minute, and the periodicity or cycles per second is shown by the following equation:

$$\text{Cycles} = \frac{\text{number of poles} \times \text{rev. per min.}}{120}$$

The following tables show the speeds for 25 and 60 cycles for which generators are usually built:

60 Cycles			25 Cycles		
3,600	1,800	1,200	1,500	750	500
900	720	600	375	300	250
514	450	400	214	187	167
225	200	180	150	125	107
164	150	120	100	94	83
100	90	80	62	58	
72					

Parallel operation is more satisfactory at low frequencies, so far as the variation in angular velocity is concerned. Due to other factors, the conditions for parallel operation depend more upon the relations between natural and impressed frequencies, rather than upon the absolute value of either.

When two synchronous machines are operated together on the same system there is a natural frequency of oscillation between them. This is represented by the following formula:

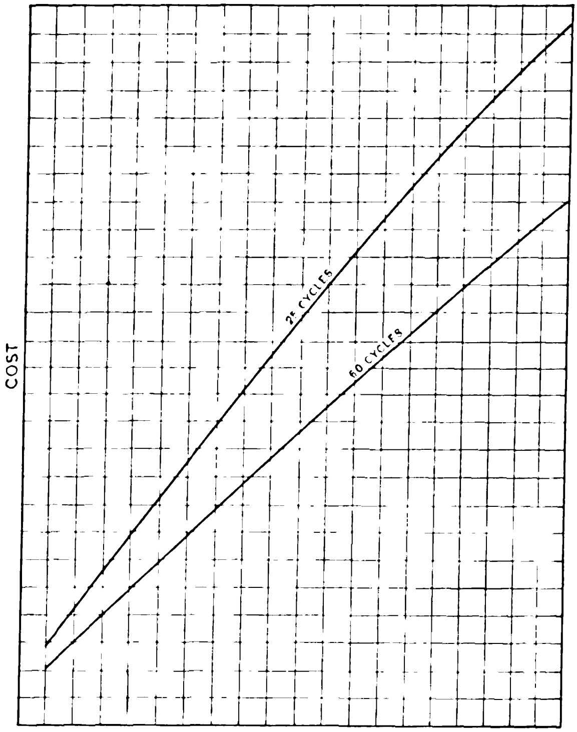
$$P_n = \frac{35{,}000}{\text{rev. per min.}} \sqrt{\frac{f \times kw. \times S_1}{WR_1^2}}$$

With reciprocating apparatus a frequency is impressed on the system by the relation of the impulses of the engine, and if this frequency approaches the natural period trouble from hunting is likely to occur.

Due to the lower core loss with lower frequencies, the efficiency is naturally better at 25 than at 60 cycles. The cost is also increased by the frequency, as shown in the curves, there being a natural tendency for 25-cycle apparatus to be heavier than 60-cycle.

Due to the fact that there is a natural relation between the windings of electrical apparatus which varies inversely as the square of the frequency, the higher the frequency the greater is, in general, the peripheral velocity at the same revolutions per minute. Increase in peripheral velocity means a larger diameter with a smaller length and a better natural ventilation.

As a general rule, the labor item is higher on the higher frequency machines, and the material item higher with the lower frequencies.



SYNCHRONOUS GENERATORS.

TRANSFORMERS

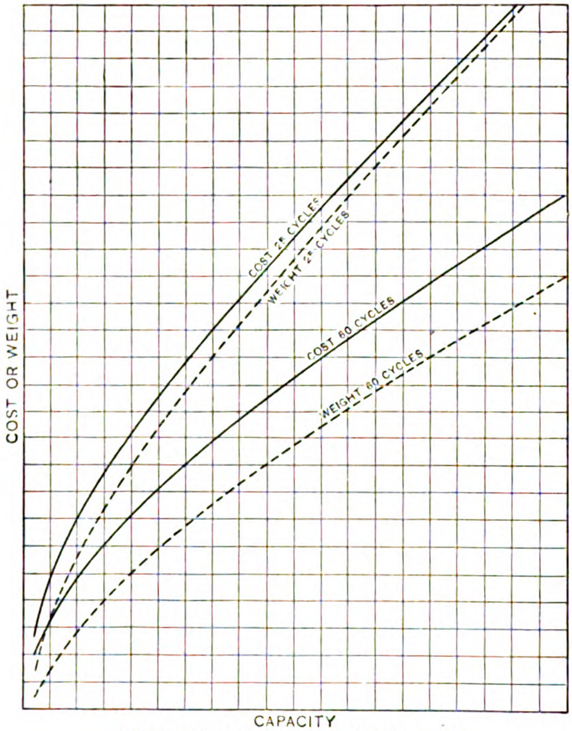
The fundamental equation for the induced e.m.f. being as follows:

$$E_1 = 4.44 f n \phi 10^8$$

it is easily seen that the influence of frequency on the design and operation of transformers is of first importance. With transformers and other electric apparatus using two windings and an iron core, the ratio of turns, other factors remaining the same, will be approximately inversely as the square root of the frequency. The lower the frequency the larger the flux, and the larger the number of turns for the same voltage. Therefore, transformers increase in cost and weight as the frequency decreases, as shown in the curves.

The regulation of 25-cycle transformers is not quite as good as for 60-cycle on account of the increased drop, due to the greater number of turns and their increased mean length.

The output of a transformer is a function of the magnetic and current densities at which the iron and copper are working, the space factor, the area of the iron and copper sections, and the frequency at which the transformer is working. With other things constant, the greater the densities at which the iron and copper are working, the greater will be the output of the transformer, while on the other hand the iron and copper losses will also be greater. The limit to which the densities may be increased is set for the core by the point of saturation of the iron and in the copper by the consideration of heating.



WATER-COOLED TRANSFORMERS.

The output as related to the frequency, with other things equal, is such that approximately

$$Kv\text{-}a. \propto f^{0.41}$$

TRANSMISSION LINES

All insulating material is supposed to be affected by dielectric hysteresis, which varies directly as the frequency. The equation for dielectric hysteresis is as follows:

$$P_d = 2 \tan \theta f C E^2$$

This has not, up to the present time, been regarded as an important factor in the breakdown of insulating materials.

Transmission lines are designed from considerations of regulation and efficiency. The regulation is better as the frequency is lower, and so for commercial work 25 cycles is preferable to 60 cycles, considering the line alone. The capacity current plays an important part with small units and high voltages, rendering it often impossible to throw one machine on the line alone. Both the reactance and the capacity current of the line are proportionate to the frequency as shown by the following equations:

$$\text{Reactance} = 2\,\pi\,f\,L$$
$$\text{Capacity current} = 2\,\pi\,f\,C\,E$$

The continued extension of voltage and length of lines will undoubtedly necessitate the use of shunt reactances across the phases to neutralize the charging current by the wattless magnetizing current, but the best result would be obtained by having the reactance automatically cut out as the load comes on the receiver circuit and increases the magnetizing current of the transmission system. For practical purposes, however, a mean value of reactance would probably be designed which would give the best results throughout the range of load under which the system is operated. The use of synchronous apparatus along the line and at the receiving end, can, of course, be made to play the same purpose as either capacity or reactance by either over- or under-exciting the machines.

In long transmission lines at the higher frequencies with an inductive load in the receiving system, trouble is not infrequently experienced by the sudden removal of the load, due to the excessive rise of voltage which limits the sensitiveness with which the lightning arresters may be adjusted, and other disturbances may also be encountered.

Many phenomena connected with the operation of transmission lines bring about electrical disturbances. The frequency of these is entirely independent of that impressed on the system. Certain quantities of electricity may be set free on the conductor, due to the discharge of lightning. After the removal of the impressing influence these oscillate with the natural frequency of the line, which is given by the following equation:

$$f_1 = \frac{7{,}900}{\sqrt{L_m C_m}}$$

It is desirable to keep the natural frequency of the system as far as possible from the operating frequency, or from a multiple of it. The apparatus connected to the line usually differs from the natural frequency to an extent which is difficult of determination.

One of the limiting features of increasing the voltage on transmission work will be the loss by corona. This is proportionate to the frequency, and may be calculated from the following formula:

$$P_c = \frac{k_1}{\delta} f \sqrt{\frac{r}{S}} (e - e_0)^2 \times 10^{-5}$$

It has been proposed to utilize corona loss as a protective measure by making the wires of the line near the power house and substations just below the normal size, so that any considerable increase in voltage would bring about its proportionate corona loss. Up to the present the determination of corona loss as regards its correction by transient voltages and magnitude of loss at the voltages which would occur, do not seem to give great promise of this as more than a slight assistance for protection. There is no reason, however, why this should not be used for what it is worth, and that many times it would be of some unknown value as a protective device.

Due to the voltage rise which takes place on long high current lines, even from the charging current, and especially where the lines are placed at different altitudes, one part of a system may be giving a considerable corona loss while another section of the line is, both in factors of voltage and altitude, below the critical point.

The resistance of wires and cables carrying alternating currents is also affected by the frequency, in that the current is not distributed uniformly over the cross-section of the conductors, the current density being higher near the periphery. . This is known as " skin effect " and results in an increased resistance. The effect is, however, negligible for low frequencies and small conductors, but increases rapidly for higher frequencies and large conductors. With magnetic material it is much higher than with non-magnetic. The equation for the skin effect coefficient is given by the following approximate formula:

$$C_s = \frac{1 + \sqrt{1 + \left(\frac{k}{\delta}\right)^2}}{2}$$

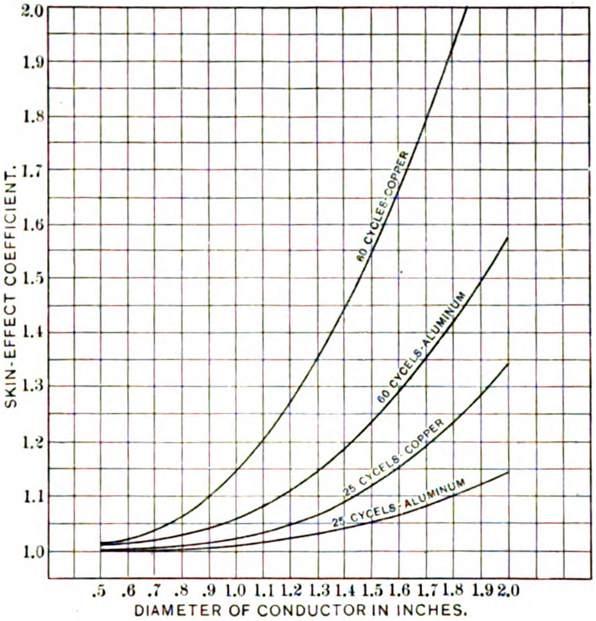
For copper $\left(\frac{k}{\delta}\right) = 0.0105\ d^2 f$

For aluminum $\left(\frac{k}{\delta}\right) = 0.0063\ d^2 f$

The values of the skin effect coefficient for copper and aluminum are given in the following curves, both for 25 and 60 cyles. For the true resistance, multiply the ohmic resistance by the skin effect coefficient.

For certain kinds of transmission work and especially for long spans, duplex metals are being used where a steel core is surrounded by a copper or aluminum cylinder, or a stranded cable wound on the steel core. The object of this, of course, is to gain additional strength from the steel while possessing the conductivity of the copper or aluminum. Such a construction could, however, be well used where any question of skin effect is presented.

The constants of an electric circuit are found in the mechanical analogues of systems possessing inertia and elasticity where the movement resulting from either is retarded by resistance. In the case of a material possessing elasticity and inertia and being disturbed by stress, the return to a condition of equilibrium is accompanied by oscillations or not, depending upon the constants of the system. This is true of the discharge of a condenser or capacity charge in an electric circuit, and is developed by the relations of the resistance, reactance and capacity. If R^2 is equal to $\frac{4L}{C}$ the discharge takes place without oscillations, but just bordering on that condition. If we have the condition R^2 less than $\frac{4L}{C}$ the charge oscillates until the energy is discharged in the resistance. Where R^2 is greater than $\frac{4L}{C}$ no oscillation takes place and no abnormal voltage is produced in the circuit. It should be recalled that the rise of voltage always takes place across the reactance. This is a specific case of a very general law.



SKIN EFFECT

LIGHTNING

The protection against high potential phenomena produced in electric circuits by atmospheric lightning is of the greatest importance in transmission systems.

Any equalization of the potential distribution in a thunder cloud above a line by a lightning flash will cause a change in the electrostatic charge of the line, corresponding to the changed potential difference between ground and cloud above ground, and the static charge thus set free on the line will move as a traveling impulse or wave along the line. The frequency of these impulses corresponds to the frequency of the lightning discharge, some having a magnitude of about one-half million cycles. Since the velocity of propagation of electric disturbances equals the velocity of light, or 188,000 miles (302,557 km.) per second, the wave length of the impulse is $\frac{188{,}000}{500{,}000} = 3/8$ mile, or about 2,000 ft. (609.6 m.).

These impulses travel along the line until their energy is dissipated, or they are reflected at the end of the line. If the latter is the case, the reflected and incoming waves may combine into a standing wave or oscillation; that is, a wave with fixed position on the line. With different oscillations superimposed upon each other, a traveling wave of moderate potential may therefore cause dangerous voltages when breaking up into oscillations, just as the rise of the ocean waves in the surf.

INDUCTION MOTORS

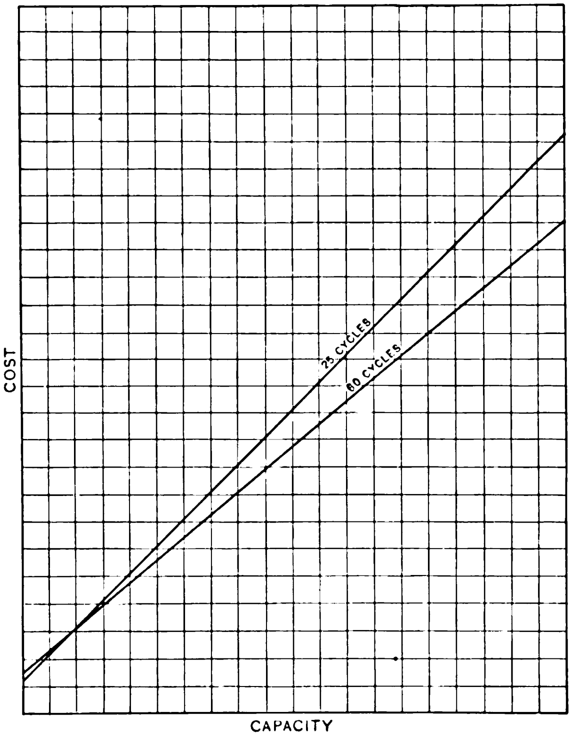
The speeds of 25-cycle induction motors for general application are practically limited to 750, 500 and 375 revolutions per minute, while the corresponding speeds for 60-cycle motors would be 1,200, 900, 720, 600, 514, 450 and 400 revolutions. Twenty-five-cycle motors could, of course, be wound for two poles, giving a speed of 1,500 revolutions, but this is rarely done except in the very small sizes. The objection is that since the flux per pole is twice as large as in the four-pole type, the section of iron back of the slots must be twice as great, for the same rotor diameter. Moreover, the end connections become very long and the machine difficult to wind and consequently the cost is very materially increased.

The efficiency depends upon a number of features. The lower frequency will, of course, tend to make the iron loss less, but on the other hand the copper loss will be considerably greater on account of the longer end connections, and as a rule, the efficiency is found to be somewhat lower for low than for high frequency motors.

The power factor of an induction motor is expressed by the ratio $\frac{\text{kw. input}}{\text{kv-a. input}}$. It is affected by the reactance and the magnetizing current. At constant line voltage the latter remains practically constant, while the former varies with the current. The shape of the power factor curve, that is, the power factor at fractional loads and overloads, therefore, depends upon the relative values of the magnetizing current and the reactance.

$$\text{Power factor} = \cos\theta = \frac{R}{Z}$$

A motor with a relatively large magnetizing current and a low reactance will in general have a low power factor at fractional loads and a rapidly increasing power factor at higher loads, while a motor with a relatively low magnetizing current and a high reactance will have a high power factor at fractional loads and only a slightly greater power factor at overloads.



INDUCTION MOTORS.

The 25-cycle motor has an inherently lower reactance and requires less magnetizing current, for which reason its power factor is considerably higher than for high frequency motors.

The starting torque and the maximum torque depend inversely on a function of the reactance, and are therefore higher for low frequencies.

The starting torque of an induction motor is equal to

$$k \frac{E^2 r_1}{Z^2}$$

The starting current is equal to

$$\frac{E}{Z}$$

The running torque is equal to

$$k \frac{E^2 s r_1}{[(r_1 + s r_2)^2 + s^2 X^2]}$$

The maximum torque is equal to

$$k \frac{E^2}{2 (r_2 + \sqrt{r_1^2 + X^2})}$$

Comparing the weights, based on motors of the same capacity and speed, it is found that, on the average, 25-cycle motors will weigh about 15 per cent more than 60-cycle motors. For the smaller sizes there is very little difference in the cost, but as the sizes increase there is a marked difference in favor of the 60-cycle motors, as shown in the curves.

SYNCHRONOUS MOTORS

The starting torque of synchronous motors is relatively small, but with the use of amortisseur windings a considerable torque is obtained at starting, particularly for lower frequencies. Any reasonable amount of torque can be provided by making the amortisseur winding of sufficiently high resistance, but the objection to this is that the higher resistance the more will the speed, up to which the rotor will be brought by the torque of this winding, fall short of synchronous speed. The ideal condition would therefore be accomplished if the starting winding could gradually be changed from one of high resistance to one of low, as the motor speeds up. This could be done by making the end rings of the armature winding of magnetic material and utilizing the " skin effect " in increasing the resistance.

At start, the currents in the end rings are naturally of the highest frequency, and consequently the skin effect and the corresponding increased resistance are also highest. As the motor speeds up the frequency of the rotor currents decreases, this in turn causing the skin effect and the increased resistance to decrease, until at synchronism the periodicity would be zero and there would be no " skin effect. " It is therefore evident that the impedance of the end rings will gradually decrease from a high to a low value as the motor gets up to speed.

When machines are driven at high speeds the choice at 25 cycles is extremely limited, and in many cases this develops a situation in which the 60 cycles is more desirable. Where, however, as is usually the case with synchronous motors, low speed apparatus is to be driven, the machinery can usually be adjusted in speed to that of the 25-cycle motor.

The wide gap in speeds with 25 cycles operated between 750 and 1500 rev.per min., with the four- and two-pole arrangement, leaves a field which it would often be desirable to utilize were it possible to do so.

FREQUENCY CHANGERS

Frequency changers are primarily used for effecting a change in frequency. They are either utilized for obtaining a frequency high enough for lighting purposes from a low frequency system. or as a means of interchanging power between systems operating at different frequencies.

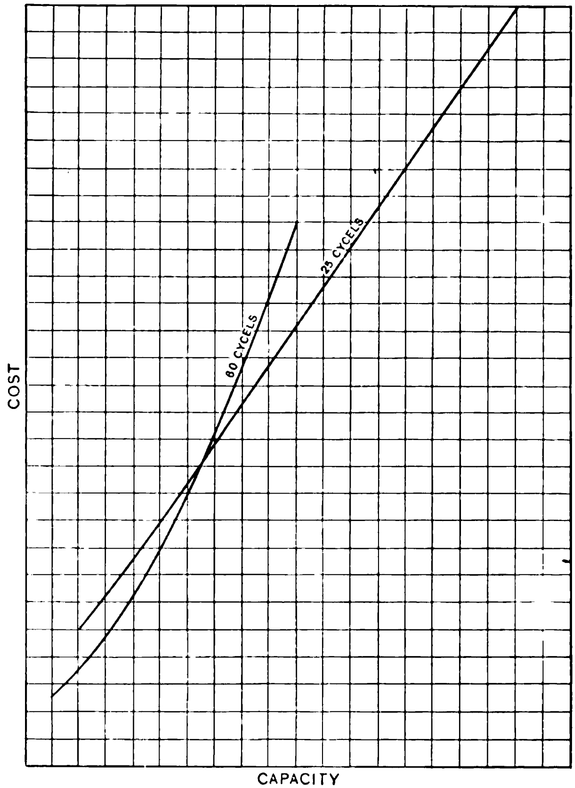
The change from 25 to 60 cycles or vice versa requires a set running at 300 rev. per min., which is a serious limitation because this speed is much too low for the economical design of frequency changers of small or moderate size. If an exact ratio is not absolutely necessary, as when power is taken from an existing system for lighting and industrial purposes, and the frequency changer is not intended for tying two generating systems together, the available range of speed is greatly increased, as shown in the following table:

FREQUENCY-CHANGER COMBINATIONS

Frequency		Poles		Speed	Generator frequency
Motor	Generator	Motor	Generator		
25	62.5	4	10	750	4.17 per cent high
25	62.5	8	20	375	4.17 per cent high
25	60	10	24	300	Exact
25	58.3	6	14	500	2.78 per cent low
25	56.3	8	18	375	6.18 per cent low
60	26.7	18	8	400	6.8 per cent high
60	25.7	14	6	514	2.8 per cent high
60	25	24	10	300	Exact
60	24	20	8	360	4 per cent low
60	24	10	4	720	4 per cent low

While synchronous motors are almost invariably used with frequency changers, induction motors may be used if proper arrangements are provided for adjusting the slip so as to insure a satisfactory parallel operation. This adjustment, of course, means the introduction of a permanent resistance and a corresponding loss, and is therefore undesirable unless other advantages of greater importance can be obtained.

Where only one set is required speed adjustment is not necessary and the motor may be designed with a slip which will just be sufficient to bring the generator frequency to the right value.



SYNCHRONOUS CONVERTERS.

Synchronous Converters

A synchronous converter being in effect a combination in one machine of a synchronous motor and a direct-current generator, the important factors in which the frequency is concerned have to do almost entirely with the continuous-current side. The continuous-current generators, as a rule, run at frequencies much below 25 cycles, and at the frequencies of synchronous converters, especially for 60 cycles and above, the problems of commutation and commutator construction become of importance.

The pole pitch on the commutator, armature or field, is the space passed through in one alternation. It is thus seen that there is a natural tendency for higher peripheral speeds at the higher frequencies, and it is the limitation of peripheral speed which fixes the limits of design.

With direct-current machines this occurs with turbine driven generators and the commutators, which are necessarily mechanical in construction, consisting, as they must, of a certain amount of insulation. Direct-current generators are therefore more limited in speeds than alternating-current, and the same holds true when they are combined as in rotary converters.

Improvements in design have made the 60-cycle synchronous converter satisfactory for the conditions under which such machines operate. At the lower frequencies, however, converters are more satisfactory in their operation, and necessarily of a greater margin of safety as regards the electrical and mechanical limits of commutation. In efficiency the 25-cycle converters are slightly higher than the 60-cycle, and the relation of costs is shown in the curves.

RAILROAD WORK

Twenty-five cycles has been recognized as the standard frequency for railway systems in this country. Until not long ago all systems were of the alternating-current-direct-current type, alternating current being generated and transmitted to the various substations, where it was changed to direct current by means of synchronous converters. The choice of this frequency was therefore chiefly caused by the less satisfactory operation of the earlier types of 60-cycle converters.

Even with the successful operation of the present 60-cycle converters, there is no reason for changing the standard 25-cycle frequency. While 60 cycles would be preferable as far as the generators and transformers are concerned, this is offset, however, by the advantages of the 25-cycle transmission system and the lower cost of synchronous converters for larger capacities. The 25-cycle lighting can also be considered as satisfactory for railway purposes.

With the introduction of the alternating-current railway motor, 60 cycles is obviously almost entirely eliminated, due to the excessive impedance drop and " skin effect " caused by the alternating-current flowing in the rails. The 25-cycle system, on the other hand, is fully satisfactory for this service, and although the 15-cycle system has been advocated, its advantages over the 25-cycle system have not been proved to be of sufficient weight to necessitate a change in the present standard frequency.

In Europe, however, a few recent single-phase systems are using this frequency.

SWITCHING PHENOMENA

The interruption of high-tension electric circuits is generally accomplished by means of oil circuit breakers so as not to produce any abnormal disturbances. The rupturing capacity of an oil circuit breaker is dependent upon the velocity with which the contacts part, their size and shape, the quality of oil, the electrical characteristics of the circuit, the length and number of breaks, etc.

The most distinctive feature of the oil circuit breaker lies in the fact that when the alternating current that is maintaining the arc in the oil passes through zero, at which point the electromagnetic energy is a minimum, the current is interrupted and remains so until the voltage rises to a sufficient value to puncture the oil insulation which has been established between the contacts. As soon as this occurs, the current re-establishes itself and flows for another half cycle. This successive going out of the arc and its re-establishment thus continues until sufficient insulation is interposed between the contacts to resist the maximum voltage of the circuit. A lower frequency is, therefore, more desirable from a switching standpoint.

ILLUMINATION

Where alternating-current is used for lighting, the 60-cycle frequency is generally used. No arc lamp has as yet been developed that will operate with entire satisfaction on frequencies of less than 40 cycles, and incandescent lamps cannot be used to advantage on frequencies of less than 30 cycles. Low voltage incandescent lamps show no flicker; but the effect of fatiguing the eye is noticeable at 25 cycles, especially in high voltage lamps.

In systems where lighting predominates a 60-cycle frequency should therefore be selected, while if most of the energy is to be used for power purposes the condition may be such that 25 cycles would prove to be preferable, in which case frequency-changers can be provided for changing the current required for lighting purposes to 60 cycles.

FREQUENCIES USED IN SOME EXISTING SYSTEMS.

	Cycles
Central Stations:	
New York Edison Company	25 and 60
Brooklyn Edison Company	25
Boston Edison Company	60
Commonwealth Edison Company	25 and 60
Detroit Edison Company	60
Transmission Systems:	
Great Western Power Company	60
Ontario Power Company	25
Sierra & San Francisco Power Company	60
Mississippi River Power Company	25
Pennsylvania Water & Power Company	25
Southern Power Company	60
Central Georgia Power Company	60
Georgia Power Company	60
Great Northern Power Company	25
Washington Water Power Company	60
Railroads:	
New York Central Railroad	25
New York, New Haven & Hartford	25
Pennsylvania Railroad	25
Great Northern Railroad	25
Butte, Anaconda & Pacific Railroad	60
Steel Mills:	
Indiana Steel Company	25
Illinois Steel Company	25
Lackawanna Steel Company	25
Carnegie Steel Company, Ohio Works	25
Youngstown Sheet & Tube Company	25
Phillips Sheet & Tin Plate Company	60
Colorado Fuel & Iron Company	60
Mines:	
Consolidation Coal Company	60
Woodward Iron Company	25
Witherbee, Sherman & Company	25
Winona Copper Company	60
Calumet & Hecla Mining Company	25
Delaware, Lackawanna & Western Railroad Company	60
Rochester & Pittsburgh Coal & Iron	25
United States Coal & Coke Company	25
Pulp and Paper Mills:	
Kimberly-Clark Paper Mill	25
St. Regis Paper Company	60
United Boxboard & Paper Company	25
Flour Mills:	
Northwestern Consolidated Milling Company	60
George Urban Milling Company	25
Washburn Crosby Company	60

Cement Mills:

Universal Portland Cement Company, Buffington	25
Inland Portland Cement Company	60
Sandusky Portland Cement Company	25
Freeport Portland Cement Company	60
Knickerbocker Portland Cement Company	60

NOTATION

C = Capacity in farads.
C_m = Capacity in microfarads.
C_s = Skin effect co-efficient.
d = Diameter of conductor in inches.
E = Applied e.m.f. in volts.
E_1 = Induced e.m.f. in volts
e = Effective applied e.m.f. in kilovolts to neutral.
e_0 = Disruptive critical voltage in effective kilovolts to neutral.
f = Frequency in cycles per second.
f_1 = Natural frequency of transmission in cycles per second.
k = Constant.
k_1 = Corona constant.
k_w = Winding factor constant.
k_f = Form factor constant.
L = Self-induction in henrys.
L_m = Self-induction in milli-henrys.
n = Number of turns.
P_c = Corona loss in kilowatts per mile.
P_d = Dielectric hysteresis loss.
P_n = Natural period in beats per minute.
R = Resistance.
R_1 = Radius of gyration in feet.
r = Radius of conductor in inches.
r_1 = Rotor resistance per phase.
r_2 = Stator resistance per phase.
S = Distance between conductors in inches.

$$S_1 = \text{Ratio } \frac{\text{Short circuit current}}{\text{Full load current}}$$

s = Slip.
W = Weight of revolving post in pounds.
X = Reactance.
Z = Impedance.
δ = Density factor.
ϕ = Magnetic flux.
θ = phase angle.

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(*Subject to final revision for the Transactions.*)

MEASUREMENTS OF VOLTAGE AND CURRENT OVER A LONG ARTIFICIAL POWER-TRANSMISSION LINE AT 25 AND 60 CYCLES PER SECOND

BY A. E. KENNELLY AND F. W. LIEBERKNECHT

It is the purpose of this paper to describe in detail a series of measurements of voltage and current over an artificial power-transmission line 1040 km. (646.2 miles) in length. Although it is readily possible to compute the behavior of such a length of line, when the linear constants are given; yet this is the first time, so far as the writers are aware, that actual observations have been forthcoming on a laboratory model power-transmission line of more than about 200 km. (130 miles) in length.[1]

The artificial line used in these measurements has been designed, constructed, and permanently installed, in the Graduate School of Applied Science at Harvard University.[2] It consists of a series of uniform reactance coils, with uniform condensers connected between them in derivation. The arrangement and connections of coils and condensers are indicated in Fig. 1. The total nominal length of line artificially imitated is 800 km. (nearly 500 miles) of three-phase line, star-connected to ground-potential neutral, as indicated in Fig. 2; or 2400 km.

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[1] J. H. Cunningham, *Design, Construction and Test of an Artificial Transmission Line*, PROCEEDINGS A. I. E. E., January, 1911, Vol. XXX, No. 1, pp. 87–93. This is described as a smooth, or distributed-capacity, single-phase line of 130 miles (209 km.) equivalent length of No. 1 B. & S. gauge copper wire, $R = 93.6$ ohms, $L = 0.394\ h$, $C = 1.135\ \mu f$.

[2] See a preliminary description "Artificial Power-Transmission Line" by A. E. Kennelly and H. Tabossi, *Electrical World*, February 17, 1912, pp. 359–361.

(nearly 1500 miles) of single-phase line to ground-potential neutral as indicated in Fig. 3.

Smooth and Lumpy Artificial Lines. As is well known, there are two principal types of artificial lines; namely *smooth* lines and *lumpy* lines. In smooth lines, the linear constants are uniformly or smoothly distributed throughout; whereas in lumpy lines, the series impedances and the derivation admittances occur in alternatively successive lumps. The line here described is a lumpy line, with lumps of series impedance for 80 km., alternating with lumps of derivation admittance for 80 km. Lumpy lines have the electrical disadvantage that a lumpiness correction-factor has to be applied to them depending upon the frequency; while smooth lines, although requiring no such corrections, are more troublesome to construct and to keep in good order.

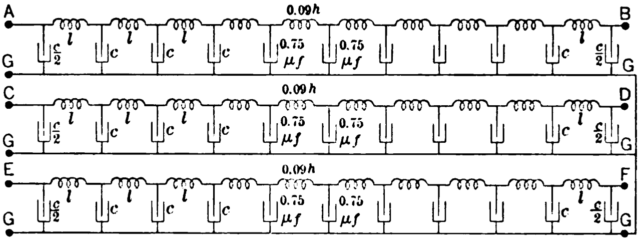

Fig. 1.—Diagram of Connections of Artificial Line.

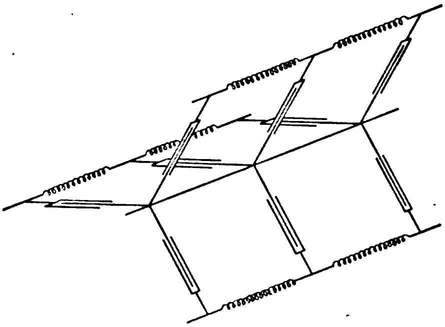

Fig. 2.—Connection of Sections when Operated as a Three-Phase Line.

T-Lines and Π-Lines. Lumpy lines may be divided into two classes; namely T-lines, and Π-lines. A T-line consists of sections each resembling a T, with a leak in the middle of the series impedance. A Π-line consists of sections each resembling a Π, with a leak at each end of the series impedance. Fig. 4 shows a T-line, and Fig. 5 a Π-line, each of four sections. It will be observed that when assembled, the only difference between a T-line and a Π-line lies in the nature of the terminal elements. In a T-line, these are half-lumps of series impedance; whereas in a Π-line they are half lumps of derivation admittance. A T-line may thus always be converted into a Π-line, or reciprocally, by the redistribution of terminal elements only. The line here described is arranged as a Π-line, for the reason that with impedance-coils virtually consisting of over-wound wooden rings, it is not easy to obtain a terminal half-impedance without the awkward expedient of using two full coils in parallel; whereas it is easy to obtain a terminal half-admittance, by splitting a full condenser.

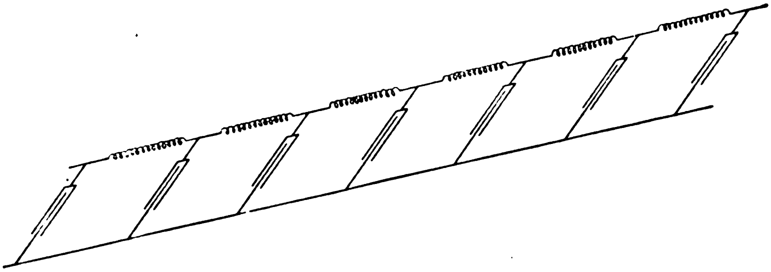

Fig. 3.—Connection of Sections when Operated as a Single-Phase Line.

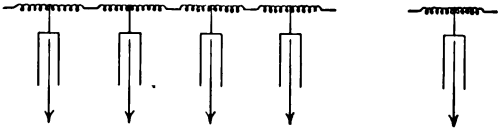

Fig. 4.—*T*-Line.

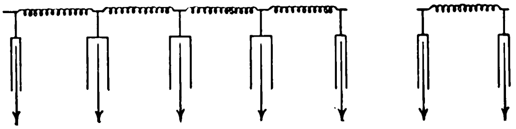

Fig. 5.—Π-Line.

Impedance Models. In Fig. 6, if *AB* is an impedance model of any actual line, in the steady working state, to any single frequency of alternating current; such that the impedance of the model to neutral or zero-potential is identical at either end *A* or *B*, to that which would be measurable on the actual line; then it will be evident that if we connect an impedance Z_r at the receiving end *B*, equal to that offered by a given load on the actual line, the steady distribution of pressures, currents, and powers, over the model system will be identical with that on the corresponding actual system, for the same impressed voltage at *A*, except within the line *AB* itself, owing to the effects of lumpiness. Also, if we make the impressed voltage on the model $1/n$th of that on the actual line, the currents in the model system will be $1/n$th those corresponding on the actual system, and the powers in the model system will be $1/n^2$ those corresponding on the actual system. Thus, in the impedance-model or artificial line here considered, the voltage impressed on the generator end *A* was usually 100 volts r.m.s., the line being an impedance model of 1040 km. (646 miles) of an actual transmission line, and the impedance Z_r at the receiving end being the impedance $Z_r = V_B/I_B$ ohms, that might well represent the actual load on such a line. Then if the working voltage on the actual line were say 100,000 volts star, or 1000 times greater than on the model, the current strength to be expected on the actual line would be 1000 times greater than were observed on the model, and the power on the actual line should be 1,000,000 times greater than those observed on the model. Each milliampere of current observed would thus correspond to one ampere in the actual case, and each observed watt to one megawatt (1000 kw.) in the actual case.

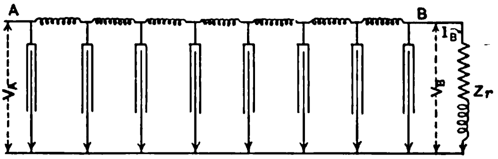

FIG. 6.—IMPEDANCE MODEL OF A SINGLE-PHASE, SINGLE-WIRE LINE AND ITS RECEIVING-END LOAD.

Impedance Coils. The impedance coils in the artificial line are all wound alike on wooden frames of standard dimensions, as shown in Fig. 7. Each limb of the frame was wound with 1190 turns, in seven layers of No. 19 A. W. G. double-cotton covered copper wire, 0.915 mm. and 1.14 mm. (0.036 in. and 0.045 in.) in bare and covered diameters. Each limb was soaked in molten paraffin wax after being wound. The junctions between the successive coils on each frame were all soldered on small terminal plates, *TTT* on the figure. The connections are such as to produce an approximately closed magnetic circuit, or continuous direction of helical windings, in order to increase the self-inductance of each main frame winding, and to diminish the external stray magnetic field as far as would be conveniently practicable. Each main frame winding contains 5.6 kg. (12.35 lb.) of wire, and has a resistance of about 23.6 ohms at 15 deg. cent., with an inductance of approximately 90 millihenrys, or a time-constant of approximately 0.0038 second.

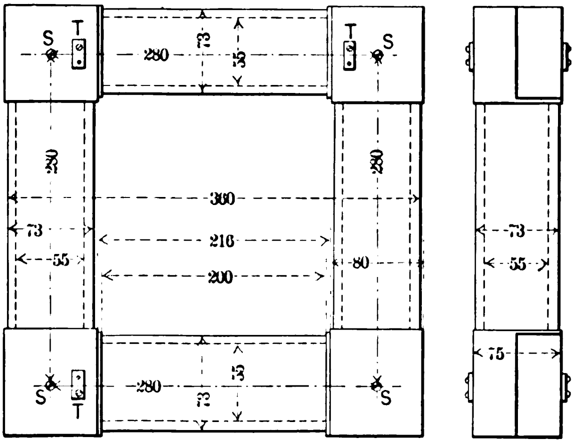

FIG. 7.—OUTLINE SKETCH OF ONE COIL. DIMENSIONS IN MILLIMETERS.

Condensers. The condensers are of tinfoil and paraffined paper. Their capacitance is about 0.75 microfarad each, except the terminal condensers, which have half this amount. The capacitance and leakance of such condensers is known to vary slightly with the frequency.[3] Each condenser was mounted in a tinned iron box 20 by 5.6 cm. wide by 14.2 cm. high (7.9 in. by 2.2 in. by 5.6 in. high), the space between condenser and box being filled in with paraffin wax.

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[3] "The Capacity and Phase Difference of Paraffined Paper Condenser as Functions of Temperature and Frequency" by F. W. Grover. *Bulletin of the Bureau of Standards*, Vol. VII, No. 4, 1911, pp. 495–578.

Mounting of the Line Elements. The connections between impedance coils and condensers being as in Fig. 1, the coils were mounted successively at right angles to each other as shown in Fig. 8; so as to reduce their mutual inductance to a negligible quantity. A simple contact plug was mounted between each pair of impedance coils, as indicated in Fig. 12, so as either to permit of the line being opened at any point, or to permit of inserting an ammeter at the point by means of a split plug.

The average electrical constants of the line elements are collected in Table I.

Assuming that each line element, *i.e.*, each lump of impedance or admittance, represents 80 km. (49.7 miles) of actual line; the corresponding linear constants of the artificial line are given in Table II, with reference both to the wire-kilometer and the wire mile. Since, in general, a lumpiness correcting factor has to be applied to these values, depending on the frequency used, these linear constants are nominal linear constants. Nevertheless, since the lumpiness correction-factor at the frequency of 60 cycles per second is only $1.0007 \backslash 0^{\circ}.03$, it is evident that, for all practical purposes, this lumpiness correction becomes negligible at or below this frequency. In general, the correction factor increases as the frequency is increased.

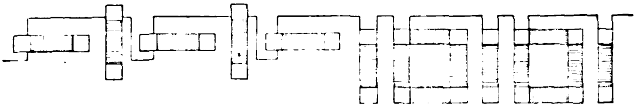


Fig. 8.—Plan and Side Elevation of Artificial-Line Coils.

The linear constants will be found to correspond substantially to those of a three-phase aerial power-transmission line consisting of three No. 000 A.W.G. aluminum stranded conductors, of 1.195 cm. (0.47 in.) overstrand diameter, equidistantly separated to interaxial distances of 230 cm. (90.5 in). All of the results reported in this paper, therefore, refer to that type of transmission-line. As to whether more satisfactory results from any given standpoint might be obtainable with a modified type of line, having say a larger size of conductor, is a question not here raised. These particular linear constants were selected in the design and construction of the artificial line, because they correspond to a well-known type of line in actual service, and it is believed that comparative results obtained on this type of line at different frequencies will be interesting and useful, whether the type could advantageously be modified or not.

Length of Line Selected for the Tests. Tests have been made on various lengths of this artificial line at different times. Those here presented were taken on a length of approximately 1,000 km. (620 miles), or actually 1,040 km. (646 miles). This represents a 13-section single-phase line. The reason for selecting this particular length was that 1000 kilometers is not likely to be exceeded in the near future of power transmission engineering, and yet it may be conceded that the behavior of a 1,000-km. single-phase line in one length, as representing one branch of a 1,000-km. three-phase line, is not without practical interest. If say 2,400 km. (1,500 miles), the full available length, had been selected, the results might have been of academic rather than of practical interest. On the other hand, the behavior of lines up to say 500 km. (300 miles) is today fairly well understood, from experience, among long-distance transmission engineers.

TABLE I.

ELECTRICAL CONSTANTS OF ELEMENTS FORMING THE ARTIFICIAL LINE.

Coils:	
Resistance of each main frame winding at 0 deg cent.	22.2 ohms.
" " " " " " " 20 " "	24.1 "
Inductance " " " " " " " " "	0.09 henry.
Time-constant " " " " " 20 " "	0.00373 second.
Condensers:	
Capacitance of each full condenser at 20 deg. cent	0.75 μf. at 60 c.p.s.
Leakance " " " " " "	9.7 μmho " "
Hyperbolic angle subtended by one Π-section	0.108 /71°.5 hyp. " "

TABLE II.

NOMINAL LINEAR CONSTANTS OF ARTIFICIAL LINE, TAKING EACH LINE-ELEMENT AS REPRESENTING 80 KM. (49.7 m.) OF WIRE.

	per wire-km	per wire-mile
Linear resistance *r* ohms at 0 deg cent.	0.278	0.445
" " " " " 20 " "	0.301	0.485
" inductance *l* henrys	1.13×10^{-3}	1.82×10^{-3}
" capacitance *c* farads	9.38×10^{-9}	15.1×10^{-9}
" leakance *g* mhos	0.12×10^{-6}	0.19×10^{-6}

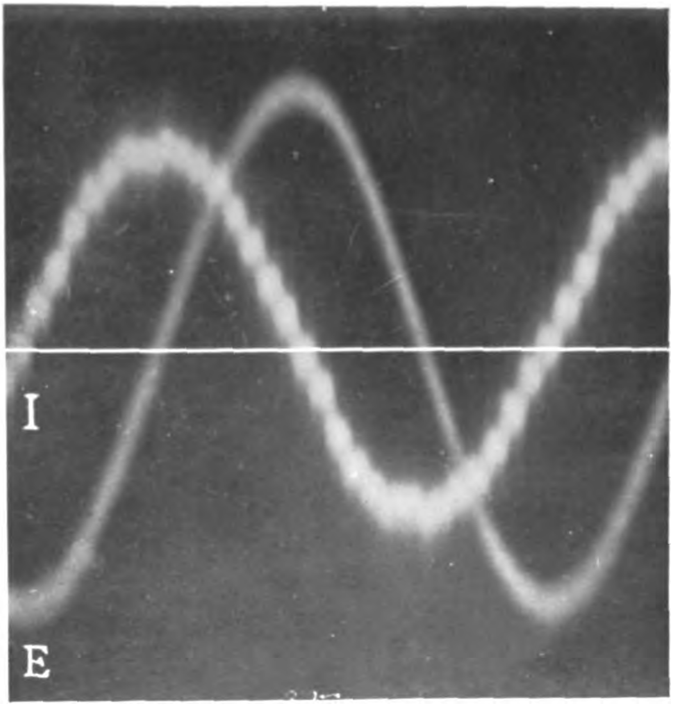
Scope of the Experimental Inquiry. The 1,000-km. artificial line was operated at the two industrial frequencies of 60 and 25 cycles per second, with and without load at the distant end. The potential and current were then measured at successive junctions, along the artificial line. The observed distributions of potential and current were then capable of being compared with those potentially obtainable on the corresponding actual line, under the assigned conditions. The measurements have thus a practical bearing, in so far as they correspond to actual line conditions, and also a theoretical bearing, in so far as they subject observations to theory.

Machinery and Apparatus Used

The three-phase alternating-current generator used in the measurements at 60 and 25 cycles per sec. was designed by Professor C. A. Adams, and had a 12-kv-a. rating. It was belt-driven by a d-c. motor. It is a six-pole revolving-field machine of the Lauffen type. The stator-armature distributed lap winding has a 4/5 pitch, and five slots per pole per phase. It gives a very close approximation to a sine wave of e.m.f., and only a very slight high-frequency harmonic ripple is found in the oscillogram of this wave. One phase only was used for operating the artificial line. An oscillogram of the wave form appears in Fig. 9. Since the current wave charging a 1.5 μf. condenser directly from 100-volt mains shows only feeble ripple derivations from the sinusoidal form, it follows that the voltage wave also appearing on the oscillogram must be a very close approximation to a sinusoid.

The operation of an artificial line at 100 volts impressed single-phase e.m.f. at the generating end, and say an inductive load of resistance and non-ferric reactance at the receiving end, is devoid of all the troubles due to switching, lightning, surges, rupture of synchronism, etc., to which an actual transmission line is subject. Moreover, the electrical distribution on an artificial line, using only a single frequency, is much simpler than that over a corresponding actual line, in which various harmonics are ordinarily present. None the less, the artificial-line distribution, after applying the proper lumpiness correction, should imitate correctly the distribution that would be found on the corresponding actual line in the steady operating state, if the fundamental frequency existed alone.

Alternating-Current Potentiometer. Both the voltage and current at successive junctions along the line were measured by a Drysdale Alternating-Current Potentiometer. A pic-



[KENNELLY AND LIEBERKNECHT]

Fig. 9.—Oscillogram of One Wave of Voltage and Current from One Delta Phase of Alternator Used Throughout Tests.

Effective voltage (r.m.s.) at time of exposure, 100.5 volts.
Current 0.08 ampere max. cyclic amplitude, charging condenser of 1.5 microfarad at 100.5 volts r.m.s.

ture of the apparatus appears in Fig. 10. As this apparatus has been fully described in technical literature,[4] a detailed description here will be unnecessary. It may suffice to say that the instrument consists essentially of a regular direct-current potentiometer, with such additional devices as will enable it to be used for measuring voltages on alternating as well as on direct-current circuits, up to 1.8 volts at terminals. In order to effect this, the potentiometer is first balanced by a Weston standard cadmium cell, with a continuous current supplied from a storage battery of eight volts. The Weston milliammeter *A*, is inserted in series with the slide wire, and should indicate just 50 milliamperes, when the balance is complete. With care, this standard current strength in the slide-wire circuit can then be reproduced, to a relatively high degree of precision, by the use of the milliammeter alone, and since the latter instrument is of the electro-dynamometer type, the slide-wire current can be adjusted either for a direct-current or alternating-current supply of 8 volts r.m.s. By means of the transformer *T*, with rotatably adjustable secondary winding, and rotating magnetic-field primary, the phase of the 8 volts, delivered single-phase from the rotatable secondary, can be

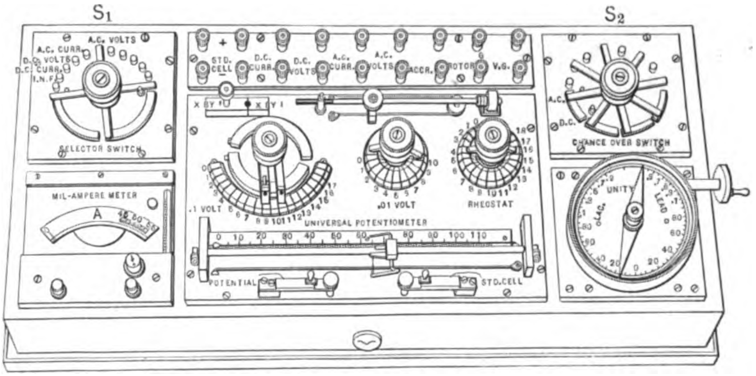


FIG. 10.—ALTERNATING AND CONTINUOUS-CURRENT POTENTIOMETER.

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[4] C. V. Drysdale: "The Use of the Potentiometer on Alternating-Current Circuits," *Phil. Mag.*, Vol. XVII, p. 402, March, 1909; also *Proc. Phys. Soc.*, London, Vol. XXI, p. 561, 1909; also *The Electrician*, London, Vol. LXIII, p. 8, April 16, 1909; also J. A. Fleming's "Propagation of Electric Currents in Telephone and Telegraph Conductors," 1911, London, p. 216.

adjusted to any desired value within say 0.1 of a degree, on the principle of a rotary-field induction voltage regulator. The rotating magnetic field in the primary is supplied by a split-phase arrangement from 100-volt single-phase mains.

The switches S_1 and S_2 are for changing direct-current to alternating-current, and for changing from one measurable potential difference to another.

The galvanometer used with alternating-current measurements may be any ordinary type of vibration galvanometer. The instrument, shown in Fig. 11, was used at the frequency of 60 cycles per sec. The vibrating magnet-mirror system is brought into tune with the alternating current to be measured by shifting the position of the soft iron magnetic shunts S, across the limbs of the flat permanent horseshoe magnet M, and so altering the controlling magnetic field intensity at the suspension.

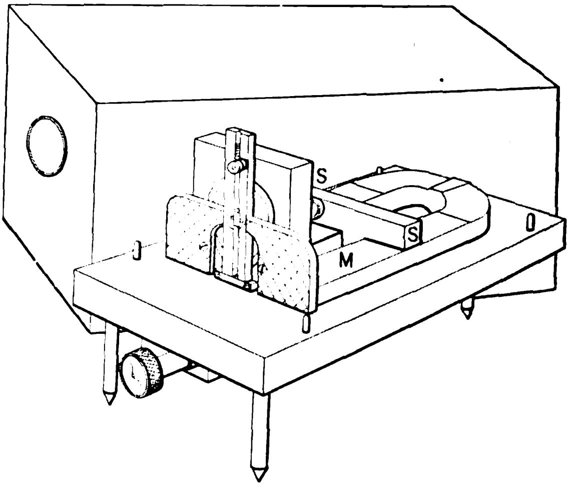

Fig. 11.—Tinsley Vibration Galvanometer.

In order then to obtain, with the vibration galvanometer in tune, zero balance in a potentiometer measurement of an alternating-current voltage, it becomes necessary to adjust both the slide-wire reading, and the phase, by alternate successive approximations, so that the voltage is finally read off both as to magnitude and phase. The instrument thus measures vector voltages, or possesses the great merit of determining voltages in two dimensions at each measurement.

The connections used on the line are indicated in Fig. 12.

By inserting a split plug into the single-plug contact piece 1, the current flowing through the second coil of the artificial line is led through a non-inductive standard strip of 0.1 ohm. The drop of potential on this 0.1 ohm resistance, as measured by the alternating current potentiometer, determines the current flowing in this section of the line, both in magnitude and phase.

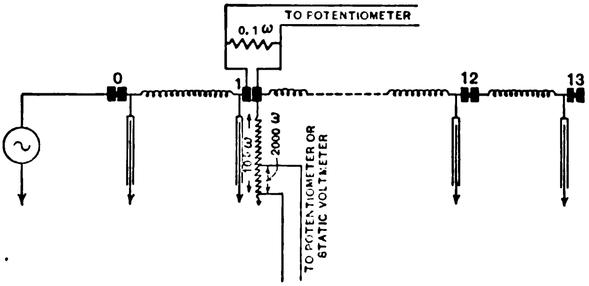

FIG. 12.—CONNECTIONS USED IN A SERIES OF MEASUREMENTS OF POTENTIAL AND CURRENT ALONG THE LINE.

The same contact piece is also connected to ground through a substantially non-inductive resistance of 100,000 ohms or more, and the potential drop over a small part of this resistance was measured by the alternating current potentiometer, both in magnitude and in phase.

Check Instruments. In order to provide a check upon the potentiometer voltage readings, both as to magnitude and phase, an electrostatic voltmeter was used as indicated in Fig. 12, and two static voltmeter readings were successively taken at each junction; namely, one from the junction to the ground, and the other from the junction to the sending end of the line. Since an alternating-current voltmeter was kept permanently connected between line and ground at the sending end, in order to insure the maintenance there of constant impressed e.m.f. during a series of measurements along the line, a voltage triangle was obtainable for each junction. Such a triangle is indicated in Fig. 13,

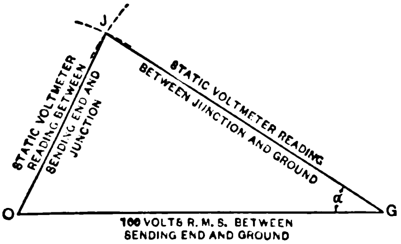
J
STATIC VOLTMETER READING BETWEEN SENDING END AND JUNCTION
STATIC VOLTMETER READING BETWEEN JUNCTION AND GROUND
α
O
G
100 VOLTS R. M. S. BETWEEN SENDING END AND GROUND

FIG. 13. — VOLTAGE TRIANGLE FOR DETERMINING THE VOLTAGE PHASE AT SUCCESSIVE JUNCTIONS ALONG THE LINE.

where GO represents, to standard phase, the constant impressed e.m.f. between ground G and sending end O, of 100 r.m.s. volts. JO represents the IZ drop between the sending end O and any given junction J, or the static-voltmeter reading between O and J; while $GJ = GO-IZ$, is the potential from ground to this junction, or the static voltage as measured between the junction and ground. Keeping GO constant and measuring OJ as well as GJ, the phase angle of lag, $\alpha = OGJ$ was subsequently measured graphically on the drawing board by a large-scale construction.

As regards checking the potentiometer readings of current, it was not practicable to check the phase; but the magnitude was checked by inserting an alternating-current ammeter or milliammeter in circuit with the resistance of 0.1 ohm at the split plug. It was found, however, that the impedance of any available good alternating-current milliammeter, of sufficient precision to constitute a check on the potentiometer observations, was very large by comparison with 0.1 ohm. In fact, after a number of measurements had been taken with a check milliammeter in circuit, it was found that the impedance of that instrument seriously vitiated the results, and the measurements had all to be repeated without the milliammeter, except for special insertions and momentary potentiometer checks. This means that owing to the relatively high sensibility to alternating-currents inherent in any good vibration galvanometer, an alternating-current potentiometer used as an ammeter is much more sensitive than an alternating-current milliammeter, since it only requires the insertion of 0.1 ohm into the circuit, besides giving a measurement of the phase as well as the magnitude of the current.

Static Voltmeters. Two types of static voltmeter were used; namely, a Kelvin multicellular voltmeter by White, with a scale graduated between 60 and 160 volts, and an Ayrton-Mather static voltmeter by Paul, with a reflecting mirror telescope and scale, reading from one volt up to 24 volts. For use with higher voltages, a substantially non-inductive multiplier resistance of 300,000 ohms was applied as a leak to the line, and the drop across a fractional part was measured. Both these voltmeters were employed; but the Ayrton-Mather instrument was found to be considerably the swifter. Its suspension was sufficiently dead beat to come substantially to rest in 14.5 seconds, the period being 5.8 seconds and the Naperian log. decrement 1.46 for a single vibration, or half cycle.

LINE FREE AT DISTANT END. FREQUENCY 60 CYCLES PER SECOND

The first series of measurements on the 13-section or 1000-km. line, was with the distant end free, and 100 volts r.m.s. maintained at the generator end, with a frequency maintained steadily at 60.7 cycles per sec. The frequency was actually maintained close to this value by rheostatic control in the field circuit of the direct-current motor driving the alternator. The impressed voltage usually varied within one or two per cent from 100 volts during the measurements, but the observed readings of current and voltage at a junction were always reduced by simple proportion to the condition of 100.0 volts at the generator end.

Table III gives the distribution of potential and current over the line both as observed and as computed. The first column gives the number of the junction. Columns II and III give the distance of each junction from the receiving end, in kilometers and miles respectively. Column IV gives the angular distance of the junction from the receiving end in hyperbolic radians. Thus junction No. 2 is $1.189 \underline{/69°.7}$ hyps. from the receiving end. The potential at the junction is theoretically directly proportional to the cosine of this hyperbolic angle, and the values so computed are set down in column VII. The observed potentials are given in columns V and VI, by potentiometer and static voltmeter respectively. The observed currents on the far side of each junction, *i.e.*, at the mid-sections, are recorded in column VIII, as obtained by potentiometer. These currents are directly proportional to the sines of the hyperbolic angles at the mid-section points as given in column IV. The computed values appear in column IX. The only noteworthy discrepancies between observed and computed values in the Table are in the phases of the currents at the more distant portions of the line. This is perhaps to be accounted for by the relatively small potential differences measured. Thus at the last midsection, the observed current was only 0.023 ampere representing a drop of 0.0023 volt in 0.1 ohm, the inserted resistance.

The results given in Table III are presented in magnitude only to rectangular coordinates in Fig. 14, in vector-diagram to polar coordinates in Fig. 15. and in perspective in Fig. 16, *VVV* is in each case the line of potential, and *III* the line of currents. It will be seen that the voltage rises about 75 per cent at the far free end over that at the generator end and

TABLE III

DISTRIBUTION OF VOLTAGE AND CURRENT OVER THE LINE AT 60.7 CYCLES PER SECOND DISTANT END FREE

Junction	Distance from receiving end.		Angular distance from receiving end Hyps.	Potential at each junction volts.						Current in each midsection amperes			
	Km.	Miles		Observed by potentiometer Magnitude	Phase	Observed by static voltmeter Magnitude	Phase	Computed Magnitude	Phase	Observed by potentiometer		Computed Magnitude.	Phase
0	1040	646.1	1.405 /69°.7	100.0	\0°			100.0	\0°	0.506	/41°.9	0.506	/41°.9
1	960	596	1.297 "	102.8	\11°.8	101.8		102.4	\11°.2				
			1.243 "							0.475	/38°.0	0.472	/38°.2
2	880	547	1.189 "	108.5	\21°.9	108.1		107.0	\21°.7				
			1.135 "							0.446	/36°.2	0.446	/36°.3
3	800	497	1.081 "	115.3	\30°.6	115.5	\30°.5	114.6	\30°.5				
			1.027 "							0.414	/34°.2	0.416	/34°.7
4	720	447	0.973 "	123.7	\37°.5	124.0	\37°.9	121.1	\36°.1				
			0.919 "							0.377	/33°.0	0.383	/33°.3
5	640	398	0.865 "	132.5	\43° 2	132.8	\43°.0	132.2	\43°.1				
			0.811 "							0.344	/31°.1	0.345	/32°.0
6	560	348	0.757 "	140.7	\47°.7	141.2	\48°.0	141.5	\47°.7				
			0.703 "							0.305	/30°	0.305	/31°.0
7	480	298	0.649 "	149.2	\51°.2	148.3	\52°.2	149.8	\51°.4				
			0.594 "							0.262	/28°.5	0.266	/30°.1
8	400	249	0.540 "	155.7	\53°.9	155.7	\54°.5	157.7	\54°.3				
			0.486 "							0.214	/28°.1	0.210	/29°.2
9	320	199	0.432 "	161.5	\57°.0	161.8	\56°.8	164.1	\56°.5				
			0.375 "							0.170	/25°.4	0.166	/28°.7
10	240	149	0.324 "	166.0	\58°.7	167.0	\58°.7	169.4	\58°.2				
			0.270 "							0.124	/25°.0	0.124	/28°.3
11	160	99.4	0.216 "	169.7	\60°.0	170.7	\59°.4	173.4	\59°.3				
			0.162 "							0.077	/21°.7	0.074	/28°.0
12	80	49.7	0.108 "	172.6	\60°.9	172.0	\60°.8	175.8	\60°.0				
			0.054 "							0.023	/20°.5	0.023	/27°.9
13	0	0	0	173.8	\61°.0	173.3	\60°.8	176.6	\60°.2				
I	II	III	IV	V		VI		VII		VIII		IX	

lags 61 deg. behind the phase of the impressed generator end potential. The power given to the line is

$$100 \times 0.506 \cos 41.9 \text{ deg} = 50.6 \times 0.7443 = 37.67 \text{ watts.}$$

If the generator end voltage were increased say 1000 times or to 100 kv., the current at the generator end would be 506 amperes, and the power absorbed by the line 37.67 megawatts (37,670 kw.) assuming no corona loss; *i.e.*, 36.2 kw. per km. (58.3, kw. per mile.)

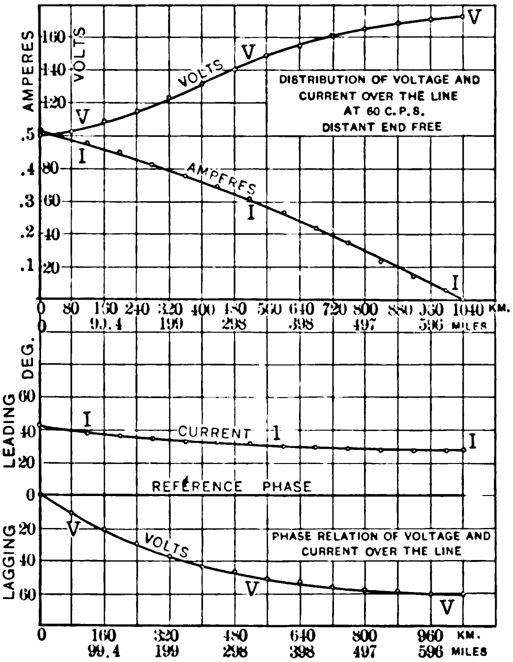

FIG. 14.—VOLTAGE, CURRENT AND PHASE RELATIONS ALONG LINE AT 60 CYCLES PER SECOND AND NO-LOAD. RECTANGULAR CO-ORDINATES.

LINE LOADED AT RECEIVING END WITH 1865 OHMS NON-INDUCTIVE, AT 60 CYCLES PER SECOND

In order to represent a simple non-inductive load at the receiving end of the line, a non-inductive resistance of 1865 ohms was connected to that end to ground, as shown in Fig. 6. The power delivered through this terminal load was 126.7 volts × 0.0675 ampere = 8.554 watts. The power delivered under these conditions at the generator end was $100 \underline{/0^\circ}$ volts $\times\, 0.398 \underline{/34^\circ.7}$ amperes $= 39.8 \underline{/34^\circ.7}$ watts $= 32.72 + j\, 22.66$

TABLE IV.

DISTRIBUTION OF VOLTAGE AND CURRENT OVER THE LINE AT 60.7 CYCLES PER SECOND.

DISTANT END LOADED WITH 1865 /0° OHMS.

Junction	Angular distance from receiving end Hyps.		Potentials at junctions, volts						Currents at mid-sections amperes			
			Observed by potentiometer		Observed by static voltmeter		Computed		Observed by potentiometer		Computed	
			Magnitude	Phase	Magnitude	Phase	Magnitude	Phase	Magnitude	Phase	Magnitude	Phase
0	2.896	/76.4	100.0	\0°	99.7	\0°	100.0	\0°	0.398	/34°.7	0.393	/36°.5
1	2.787	/76.6	100.0	\10°.4	99.7				0.374	/29°.8		
2	2.680	/76.9	100.8	\18°.3	101.1				0.346	/26°.8		
3	2.572	/77.2	103.5	\26°.4	103.4				0.323	/23°.9		
4	2.466	/77.6	106.5	\32°.9	106.5	\33.0			0.293	/21°.2		
5	2.361	/77.9	110.4	\38.65	110.6	\39.75			0.270	/17°.1		
6	2.252	/78.3	115.2	\44°.4	114.3	\44.2			0.240	/14°.2		
7	2.145	/79.7	117.4	\48°.5	118.3	\48.5			0.209	/10°.3		
8	2.040	/79°.2	121.8	\52°.1	121.4	\52.1			0.177	/5°.2		
9	1.931	/79°.7	123.4	\55°6	124.4	\55°.1			0.145	\1°.4		
10	1.827	/80°.0	125.4	\58.2	126.0	\58.0			0.119	\10°.3		
11	1.721	/81°.	126.4	\60.1	126.5	\60.0			0.093	\23°.9		
12	1.615	/81°.8	126.5	\62°.1	126.5	\62.8			0.069	\45°.6		
13	1.508	/82°.6	126.6	\63°.5	126.5	\63.6	126.7	\61°.5	0.0675	\62°.2	0.06794	\61°.5
I	IV		V		VI		VII		VIII		IX	

watts; so that the efficiency of the line under this load was 8.554/32.72 = 0.2614. The conditions along the line are presented in Table IV, where the columns are numbered beneath to correspond with those of Table III already considered. The angle subtended by the load is 1.508 /82°.6 hyp. radians,

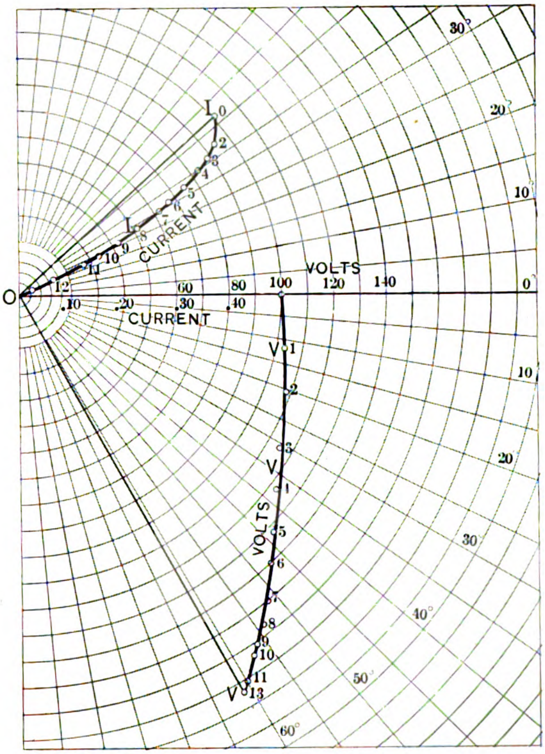

Fig. 15.—Curves Showing Phase Relations of Voltage and Current for Points on the open Line.

and this adds up to 2.896 /76°.4 hyp. radians at the generating end. The junction voltages along the lines are directly proportional to the hyperbolic sines, and the current strengths to the hyperbolic cosines of these angles.

The distributions of potential and current along the line are presented to rectangular coordinates in Fig. 17, to polar coordinates in Fig. 18, and in perspective projection in Fig. 19. It will be seen that the receiving-end voltage is much less than

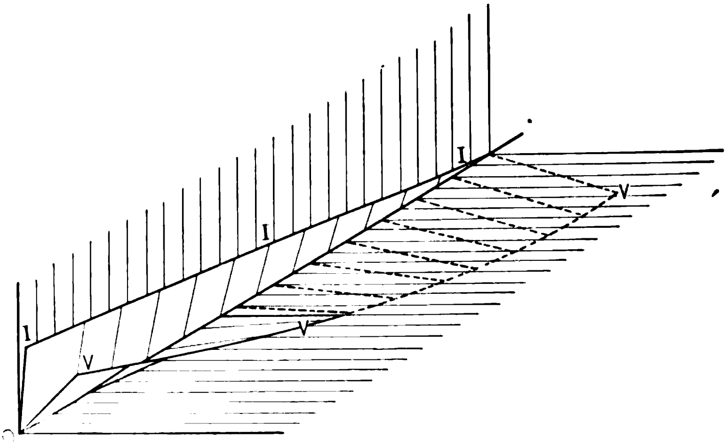

FIG. 16.—LINE FREE AT DISTANT END—60 CYCLES PER SECOND.

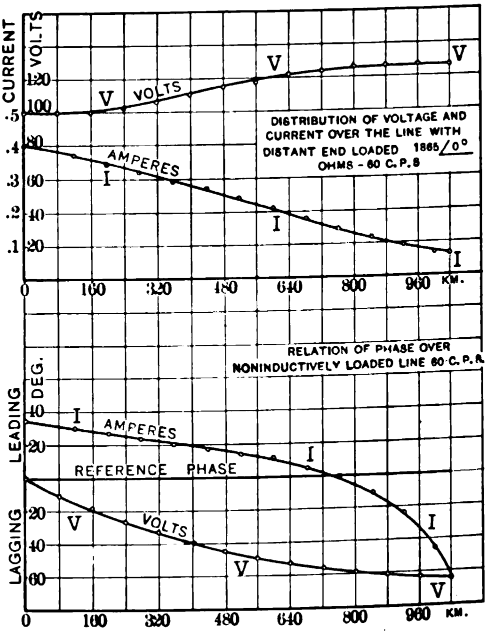

FIG. 17.—VOLTAGE, CURRENT AND PHASE RELATIONS ALONG THE LINE AT 60 CYCLES PER SECOND AND NON-INDUCTIVE LOAD. RECTANGULAR CO-ORDINATES.

at no load, but is still 26.5 per cent above the generating-end voltage. The current strength entering the line at the generating end is nearly six times as great as that entering the load at the receiving end. If the frequency could be reduced to zero, or to the continuous-current condition, still keeping the voltage applied at the generating end, the efficiency of the line should be 1865/2199 = 0.848. The line current would also be the same at each end, if negligible leakage existed. Consequently, the effects of distributed inductance and capacity at 60~, on 1000 km. of this line, bring the line-efficiency down to one-third, and raise the line current to six times the values corresponding theoretically to zero frequency.

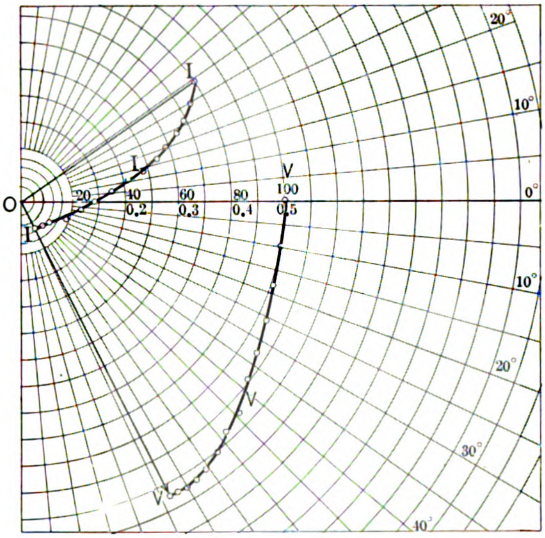

Fig. 18.—Relations of Vector Voltage and Current at 60.7 Cycles per Second with Non-Inductive Load.

Line Loaded at the Receiving End with an Inductively Reactive Load of 1635/17°.1 Ohms, or Power-Factor of 95.6 Per Cent

In order to improve the regulation of the line, an inductive load of power factor 0.956 was applied at the receiving end. This load was composed of non-ferric inductance coils, since it

TABLE V.

DISTRIBUTION OF VOLTAGE AND CURRENT OVER THE LINE AT 60.7 CYCLES PER SECOND.

DISTANT END LOADED WITH 1635 /17°.1 OHMS.

Junction	Angular Distance from receiving end Hyps.		Potentials at junctions, volts						Currents at mid-section amperes			
			Observed by potentiometer		Observed by static voltmeter		Computed		Observed by Potentiometer		Computed	
			Magnitude	Phase	Magnitude	Phase	Magnitude	Phase	Magnitude	Phase	Magnitude	Phase
0	2.832	/76.2	100.0	\0°	100.4	\0°	100.0	\0°	0.384	/37°.6	0.375	/39°.8
1	2.714	/76.4	100.8	\8°.4	100.7				0.352	/32°.7		
2	2.617	/76.7	103.7	\17°.3	102.8				0.325	/29°.5		
3	2.510	/77.0	105.5	\24°.4	105.8				0.301	/26°.2		
4	2.402	/77.3	109.1	\31°.0	109.1	\30°.6			0.272	/23°.2		
5	2.295	/77.7	112.3	\36°.1	112.2	\36°.6			0.248	/19°.2		
6	2.189	/78.1	116.0	\41°.1	115.4	\41°.1			0.217	/15°.7		
7	2.082	/78.5	119.0	\45°.1	118.6	\45°.5			0.188	/10°.6		
8	1.975	/79.0	121.8	\48°.5	121.8	\48°.5			0.155	/ 4°.3		
9	1.869	/79.5	123.5	\51°.6	122.8	\51°.5			0.129	\ 4°.6		
10	1.762	/80.2	124.3	\54°.0	124.5	\53°.8			0.103	\15°.8		
11	1.656	/80.8	124.1	\55°.9	124.5	\55°.6			0.082	\34°.8		
12	1.550	/81.6	122.8	\57°.5	123.7	\57°.5			0.076	\62°.5		
13	1.445	/82.5	121.0	\58.4	121.3	\58.4	122.4	\56.4	0.074	\75°.5	0.0749	\73°.5
I	IV		V		VI		VII		VIII		IX	

was desired to avoid introducing harmonic frequencies in the current by using ferric inductance coils; *i.e.*, inductance coils with iron cores. The results are given in Table V. The power delivered at the receiving end was

$121.0\,\underline{/0^\circ}$ volts $\times\ 0.0742\,\overline{\backslash 17^\circ.1} = 8.978\,\overline{\backslash 17^\circ.1}$ watts $= 8.582 - j\,2.64$ watts, or 8.582 watts of active power, and 2.64 watts of reactive power. The power at the sending end of the line was

$100\,\underline{/0^\circ} \times 0.384\,\underline{/37^\circ.6} = 38.4\,\underline{/37.6}$ watts $= 30.43 + j\,23.43$ watts. The efficiency of the line was thus $8.582/30.43 = 0.282$, or slightly better than on non-inductive load. The angle subtended by the load was $1.445\,\underline{/82^\circ.5}$ hyp. radians, and that at the sending end of the line $2.832\,\underline{/76^\circ.2}$ hyp. radians. As before, the junction voltages are directly proportional to the hyperbolic sines and the current strengths to the hyperbolic cosines of these angles.

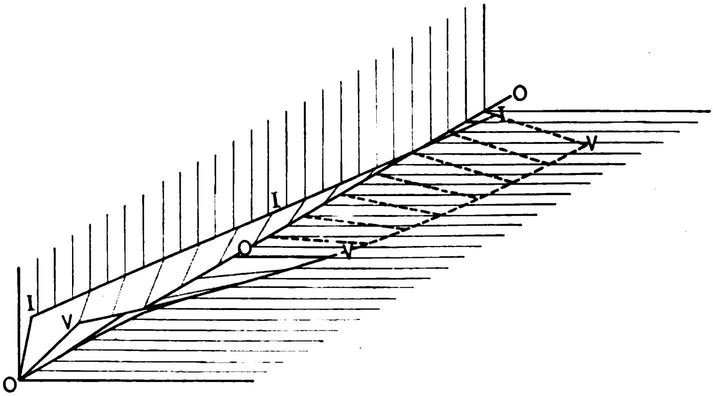

Fig. 19.—Line Non-Inductively Loaded—60 Cycles per Second

The distributions of potential and current along the line with inductive load are presented in Figs. 20, 21, 22, to rectangular, polar, and perspectively projected, coordinates, respectively. It will be seen that the distant-end voltage is 121 volts as against 126.6 volts with non-inductive load; or the regulation of voltage is somewhat improved by the reactance in the load. If this reactance could conveniently have been increased and the power-factor further lowered, the improvement in regulation would have been still better.

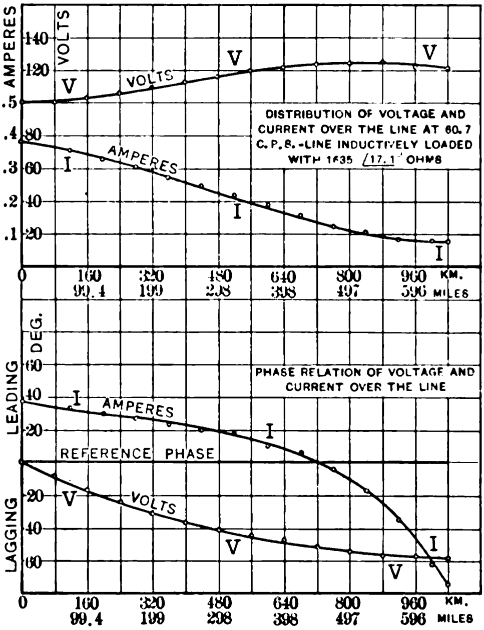

FIG. 20

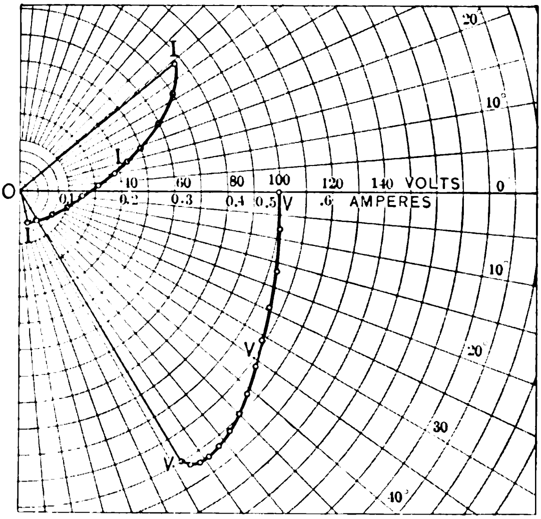

FIG. 21.—RELATIONS OF VECTOR VOLTAGE AND CURRENT AT 60.7 CYCLES PER SECOND WITH INDUCTIVE LOAD.

TESTS AT 25 CYCLES PER SECOND. LINE FREED AT FAR END

The same 13-section 1040-km. artificial line was operated at 25.4, instead of at 60.7, cycles per second, both at no load and at non-inductive load. The results are recorded for the no-load case in Table VI.

It will be seen that the measurements were not made in this case with the alternating potentiometer, as at that time the writers had not found how to tune the vibration galvanometer for the reduced frequency, actually a very simple matter. The voltages were all measured by the Ayrton-Mather static voltmeter, and their phases by the graphical method indicated in Fig. 13. The currents were measured only by ammeters.

TABLE VI.

DISTRIBUTION OF VOLTAGE AND CURRENT OVER THE LINE AT 25.4 CYCLES PER SECOND FOR NO LOAD CONDITION OR DISTANT END FREE.

Junction	Angular distance from receiving end Hyps.		Potentials at junctions, volts				Currents at mid-sections amperes		
			Observed by static voltmeter r.m.s. volts		Computed r.m.s. volts		Observed by Ammeter	Computed	
			Magnitude	Phase	Magnitude	Phase	Magnitude	Magnitude	Phase
0	0.767	57°.4	100.0	0°	100.0	\0°	0.1666	0.173	72°.3
1	0.708	"	101.1	\2°.1	101.1	\2°.7			
							0.152	0.155	70°.5
2	0.649	"	102.3	\4°.7	102.1	\5°.1			
							0.139	0.141	69°.8
3	0.590	"	103.4	\7°.0	103.2	\7°.3			
							0.124	0.128	69°.2
4	0.531	"	104.6	\9°.0	104.3	\9°.2			
							0.111	0.115	68°.8
5	0.472	"	105.7	\10°.7	105.4	\10°.8			
							0.100	0.101	68°.1
6	0.413	"	106.9	\11°.9	106.4	\12°.2			
							0.086	0.090	67°.7
7	0.354	"	108.0	\13°.2	107.5	\13°.4			
								0.076	67°.3
8	0.295	"	108.6	\14°.2	108.3	\14°.4			
								0.062	66°.9
9	0.236	"	109.1	\15°.0	108.9	15°.3			
								0.048	66°.7
10	0.177	"	109.4	\15°.6	109.5	\15°.9			
								0.034	66°.6
11	0.118	"	109.7	\16°.1	109.9	\16°.2			
								0.021	66°.4
12	0.059	"	110.0	\16°.4	110.1	\16°.4			
								0.007	66°.4
13	0	"	110.3	\16°.7	110.5	\16°.5	0.0	0.0	
I	IV		V		VII		VIII	IX	

The distributions of potential and current over the line are shown in Figs. 23, 24 and 25. It will be seen that the Ferranti effect multiplier is only 1.10 at this frequency, instead of 1.74 at

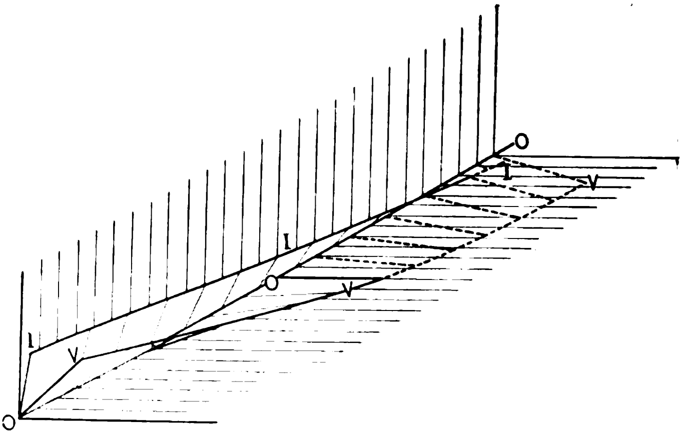

FIG. 22.—LINE INDUCTIVELY LOADED—60 CYCLES PER SECOND.

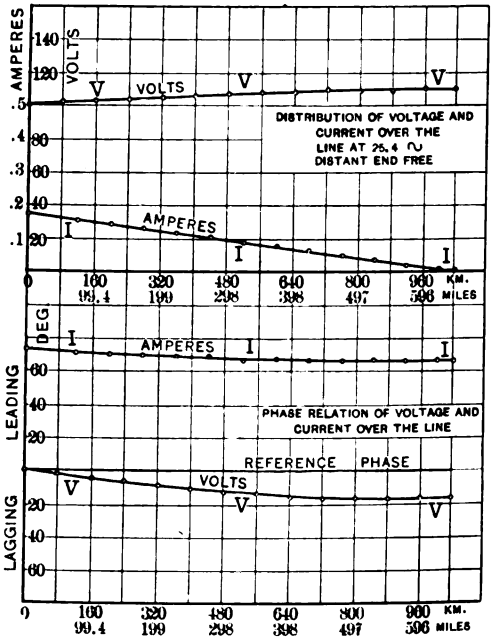

FIG. 23—FREQUENCY 25.4 CYCLES PER SECOND. DISTANT END FREE.

60.7 cycles per second. That is the rise of potential at the distant free end is only 10 per cent.

LINE LOADED AT DISTANT END, NON-INDUCTIVELY WITH 2000 /0° OHMS, 25 CYCLES PER SECOND

The same 13-section artificial line was loaded with 2000 /0° ohms at the receiving end, for a frequency maintained at 25.4 cycles per second. The results are recorded in Table VII. The power delivered to the line at the generator end was 100 /0° × 0.162 /54.2° = 16.2 /54.9 watts = 9.32 + *j* 13.25 watts; while the power delivered to the load at the receiving end was 93.3 /0° × 0.04665 /0° = 4.35 watts; so that the efficiency of the line was 4.35/9.32 = 0.467. The power-factor of the line at the generating end was, by computation, 0.575, and the current strength entering the line at the generating end was 3.47 times the current strength entering the load at the receiving end. The

TABLE VII.

DISTRIBUTION OF VOLTAGE AND CURRENT ON THE LINE AT 25.4 CYCLES PER SECOND FOR THE CONDITION OF NON-INDUCTIVE LOAD 2000 /0° OHMS AT RECEIVING END.

	Angular distance from receiving end Hyps.		Potentials at junctions volts				Currents at mid-sections Amperes		
			Observed by static voltmeter		Computed		Observed by ammeter	Computed	
			Magnitude	Phase	Magnitude	Phase			
0	2.199	/73°.5	100.0	\0°	100.0	\0°	0.162	0.164	/54°.9
1			99.6	\2°.45	99.9	\ 2°.2			
							0.147	0.148	/51°.8
2			99.36	\5° 16	99.2	\4°.8			
							0.131	0.137	/49°.5
3			99.12	\7°.33	99.1	\7°.0			
							0.120	0.126	/46°.8
4			98.86	\9°.3	98.8	\9°.2			
							0.110	0.116	/44°.2
5			98.51	\11°.09	98.8	\10°.9			
							0.101	0.105	/40°.8
6			98.12	\12°.83	98.5	\12°.7			
							0.088	0.094	/37°.1
7			97.66	\14°.33	97.7	\14°.0			
								0.084	/32°.5
8			97.18	\15°.5	97.5	\15°.1			
								0.074	/26°.5
9			96.68	\16°.6	96.8	\16°.5			
								0.065	/20°.1
10			96.10	\17°.6	96.1	\17°.5			
								0.057	/11°.0
11			95.36	\18°.6	95.1	\18°.3			
								0.052	/0°.8
12			94.22	\19°.25	94.3	\19°.0			
								0.048	\12°.2
13	1.478	/81°.8	93.06	\19°.6	93.3	\19°.6	0.0467	0.0468	\19°.6

actual ohmic resistance of the line on the occasion of the test was 308.7 ohms; so that, if operated at frequency 0, *i.e.*, by direct current, the line efficiency would be 2000/2308.7 = 0.866. The effect of the inductance and capacity of the line was therefore to reduce the line efficiency to roughly one-half what might be obtainable theoretically, at the same voltage, with continuous currents.

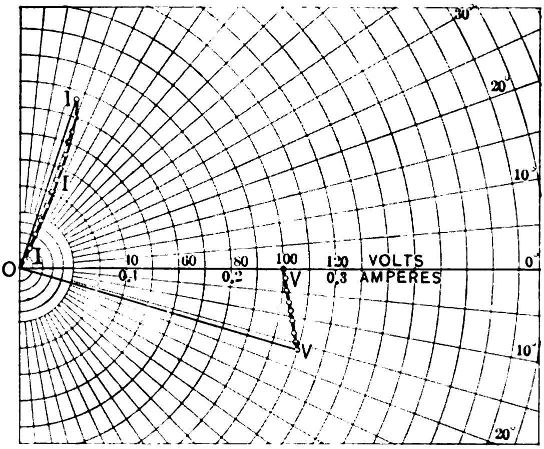

FIG. 24.—RELATIONS OF VECTOR VOLTAGE AND CURRENT AT 25.4 CYCLES PER SECOND. DISTANT END FREE.

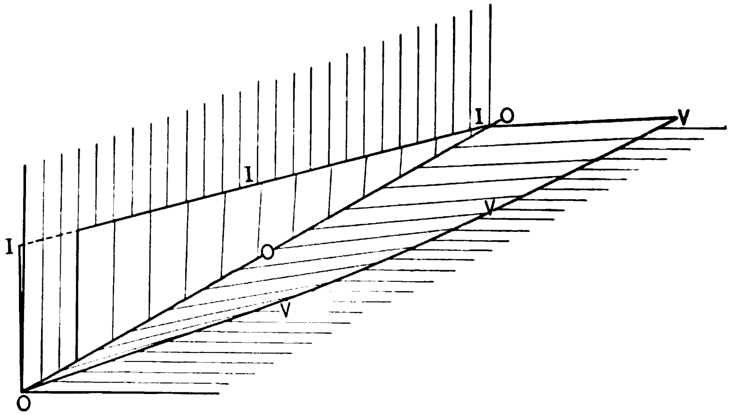

FIG. 25.—LINE FREE AT DISTANT END—25 CYCLES PER SECOND.

The distributions of voltage and current over the line are indicated graphically in Figs 26, 27 and 28.

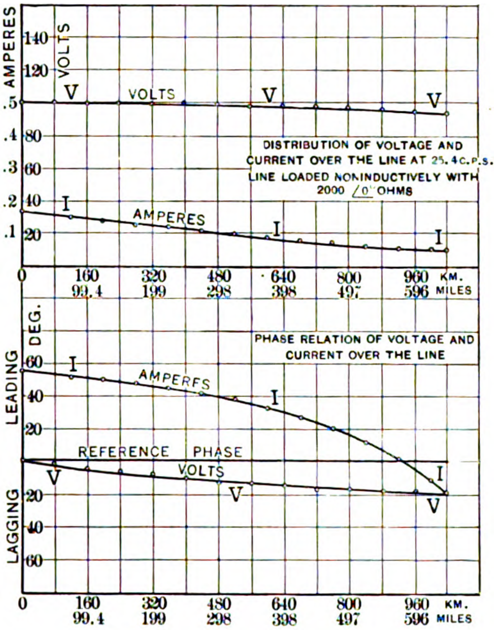

FIG. 26

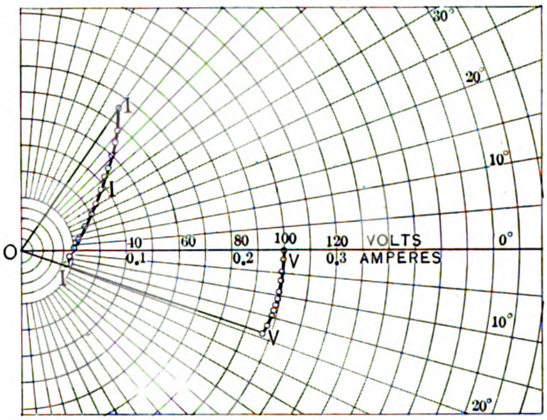

FIG. 27.—RELATIONS OF VECTOR VOLTAGE AND CURRENT AT 25.4 CYCLES PER SECOND—NON-INDUCTIVE LOAD.

EQUIVALENT CIRCUITS OF THE LINE AT 60 AND AT 25 CYCLES PER SECOND

In Fig. 29 the nominal Π of the line is shown on the left hand, for the 13-section 1040-km. line, at the frequency of 60.7~. The conductor *A B* contains the actual series impedance of the line; namely $333.8 + j\ 417.5 = 534.6\ \underline{/51^\circ.35}$ ohms. Each of the two terminal leaks *A G*, *B G*, contains half the actual shunt admittance; namely $(0.0628 + j\ 1.845)10^{3} = 1.846 \times 10^{-3}\ \underline{/88^\circ.05}$ mho. That is, half the capacity of the line is placed at each end, and its admittance indicated for the frequency of 60.7~. On the right hand side of the same figure is the equivalent

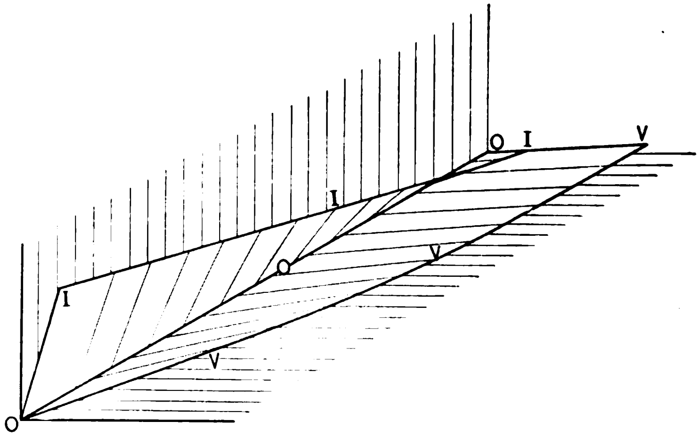

FIG. 28.—LINE NON-INDUCTIVELY LOADED—25 CYCLES PER SECOND.

Π of the line, or that particular Π which behaves in all external respects like the actual line for this particular frequency. The series impedance *A′ B′* becomes $176.9 + j\,377.1 = 416.5\ \underline{/64^\circ.87}$ ohms, and each shunt admittance *A′ G′*, *B′ G′*, becomes $(0.3357 + j\,2.065)10^{-3} = 2.092 \times 10^{-3}/80.77^\circ$ mhos. In order to ascertain how the actual line will behave at and beyond its terminals, under any assigned set of terminal conditions, such as 100 $/0^\circ$ volts at *A′*, and a load of 1865 $/0^\circ$ ohms at *B*, we have only to apply that load to the equivalent Π and compute the results by Ohm's law. The results check those obtained in the tables by other methods. The equivalent Π gives, however, no information concerning the distribution of current and voltage at intermediate points along the line;[5] because in the equivalent Π, the fall of potential along the line $A'B'$ is a vector straight line, and the current entering the line series-section $A'B'$ at A', is the same as leaves that section at B'.

Similarly, Fig. 30 gives the nominal and equivalent Πs for the same line at 25.4 ~, except that owing to the combined effects of eddy currents and change of temperature, the actual ohmic resistance of the line was 308.7 ohms at 25.4 ~ and 333.8 ohms at 60.7 ~.

Application of Results to Shorter Lines of the Same Type.

Although all of the observations recorded in this paper refer to a line of 1040 km. (646 miles) in length, yet they may be made applicable to lines of the same type of any length less than this, under the same impedance load at the receiving end. Thus, if we consider a line of 480 km. (298 m.) in length, operated at the pure frequency of 60 ~, we find from Table III and Figs. 14, 15 and 16, that, under no load, the voltage at the far end would be $173.8 \backslash\overline{61^\circ}.0$ with $149.2 \backslash\overline{51^\circ}.2$ at the sending end, a Ferranti-effect rise of $1.165 \backslash\overline{9^\circ}.8$. The charging current would be $0.28 \underline{/30^\circ}$ amperes at $149.2 \backslash\overline{51^\circ}.2$ volts. With a load of $1865 \underline{/0^\circ}$ ohms, the voltage would rise along the line from $118 \backslash\overline{48^\circ}.5$ to $126.5 \backslash\overline{63^\circ}.5$ volts, and the current would be $0.23 \underline{/12^\circ}$ at the sending end.

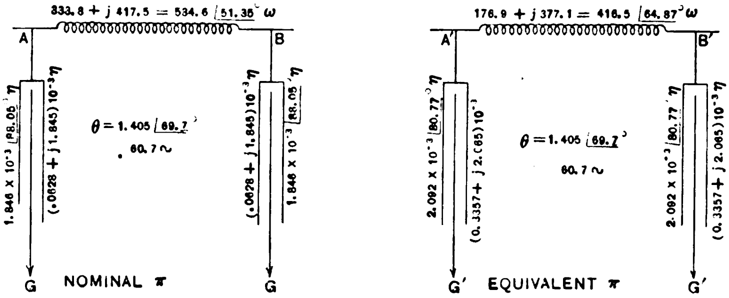

Fig. 29.—Nominal and Equivalent πs of the 1.040-km. Artificial Line at 60.7 Cycles per Second.

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[5] Transactions, A. I. E. E., Vol. XXVIII, Pt. I, June 29, 1909, p. 701. "The Application of Hyperbolic Functions to Electrical Engineering Problems," Chap. VII, *Univ. of London Press*, **1912**.

SUMMARY OF RESULTS

A single-phase artificial transmission line of 1040 km. (646 miles) of an actually existing type has been operated experimentally at 60 and 25 cycles per second, with and without load. The results are directly applicable to any single star-branch of symmetrical three-phase transmission line.

At 60 cycles per second, the no-load receiving-end voltage rose nearly 75 per cent above the sending-end voltage. With a non-inductive load, corresponding to 85 per cent efficiency in the direct-current case, the receiving-end voltage fell to 1.27 times the sending-end voltage, the line efficiency being 0.26, and the sending-end current nearly six times the current arriving at the load. On substituting an inductive load of power factor 0.956, corresponding to 82.4 per cent efficiency in the direct-current case, the receiving-end voltage fell to 1.21 times the sending-end voltage, the line efficiency being 0.28, and the sending-end current being five times the current arriving at the load.

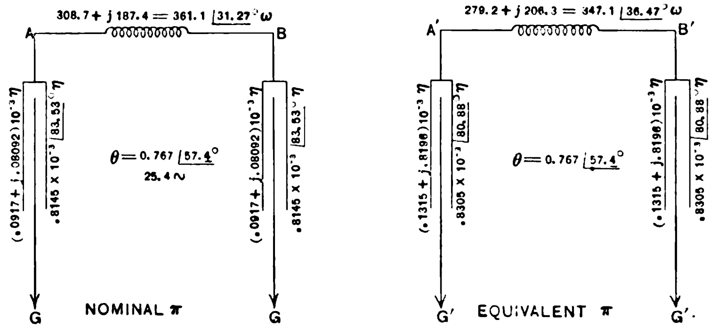

FIG. 30.—NOMINAL AND EQUIVALENT πS OF THE 1,040-KM. ARTIFICIAL LINE AT 25.4 CYCLES PER SECOND.

At 25 cycles per second, the no-load receiving-end voltage was 10 per cent above the sending-end voltage. With a non-inductive load corresponding to 87 per cent efficiency in the direct-current case, the receiving-end voltage fell to 0.93 times the sending-end voltage. The line efficiency being 0.47 and the sending-end current being 3.5 times the current arriving at the load.

Both at 60 and 25 cycles per second, the effect of applying the load at the receiving end was to reduce the current at the sending end of the line, in the 60 ~ case about 20 per cent, and in the 25 ~ case about 3 per cent.

The measurements of voltage and current along the line in the different series were mostly made in respect to phase as well as in respect to magnitude. They have been found to to check the hyperbolic-function theory of such lines within the limits of precision of the measurements.

The results as tabulated for 1040 km. are available for any shorter length of this type of line, working from the receiving end, with a pure frequency of either 60 or 25 cycles per second.

Great care has to be taken in all such measurements to keep the frequency constant and as nearly pure as possible.

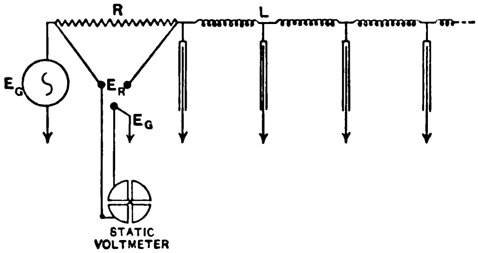

FIG. 31.—CONNECTIONS FOR SENDING-END IMPEDANCE MEASUREMENT.

APPENDIX

A METHOD OF MEASURING LINE IMPEDANCE BY STATIC VOLTMETER IN THE ABSENCE OF AN A-C. POTENTIOMETER

In order to measure the surge impedance z_0 of a line, as well as its angle θ at a given frequency, it is convenient to measure the sending-end impedance of the line, first Z_f, with the line free at the distant end, and second Z_g, with the line grounded or shorted at the distant end. It then follows that if the line is uniform

$$z_0 = \sqrt{Z_f Z_g} \qquad \text{ohms.}$$

and

$$\theta = \tanh^{-1} \sqrt{Z_g / Z_f} \qquad \text{hyps.}$$

Consequently, it is important to be able to measure the vector impedances Z_f and Z_g with a sufficient degree of precision.

A convenient method is to impress a known voltage on the line at the sending end, after inserting a non-inductive resistance into the circuit, as shown in Fig. 31. Three voltages are now to be measured in succession, while the electrical conditions are maintained as nearly uniform as possible, the frequency being carefully observed; namely E_G the voltage at generator terminals, E_R the voltage drop across the non-inductive resistance R, and E_L the voltage drop in the line. These three voltages, if plotted graphically, form a closed triangle, the sides of which being known, their relative phase displacements can be deduced, either trigonometrically or graphically. The current in the resistance R, being in phase with the voltage drop E_R, the impedance Z_L of the line can be subsequently determined. In the general case, this method is a well-known species of the three voltmeter test. It is, however, tedious to work out, since the triangle is ordinarily scalene, and can only be solved for phase angles by a relatively slow graphical or trigonometrical process. The improvement which the writers have found very convenient, and which is supposed to be new, consists in adjusting the resistance R, by successive steps, until the voltage drop E_R on R, is equal to the voltage drop E_L on the line. This means that the static voltmeter deflection on E_R is the same as that on E_L, and also that the impedance Z_L of the line, is numerically equal to the adjusted value of R. Since the voltage triangle E_G, E_R, E_L or OAG, Fig. 32, is now isosceles, it will be evident that the included angle β can be obtained without resorting to graphical construction from the relation,

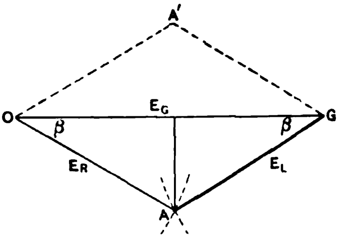

FIG. 32.—PROCESS FOR MEASURING LINE IMPEDANCE.

$$\cos \beta = (E_G/2)/E_R \qquad \text{numeric}$$

The vector diagram OAG in Fig. 32 is a voltage diagram. If, however, we divide the sides of that diagram by I_R, the known current in the resistance R, and take the resistance R as of standard phase; we obtain the diagram $Oa\,bg$ in Fig. 33, where R is, to scale, the adjusted resistance for balance, Z_L is the impedance of the line, with an angle of 2β. Both the effective resistance R_L and the effective reactance X_L of the line, are thus determinable.

The advantages of the improved method are:

1. Simplicity of computation, without the necessity of plotting.

2. The direct evaluation of the magnitude Z_L in the adjustment of R.

3. The direct observation, through successive trials, of the degree of constancy of Z_L.

The test is taken first with the distant end of the line free to obtain Z_f, and then with the distant end grounded, to obtain Z_g. It is found, in practice, that if the frequency impressed on the line can be held constant, R can be adjusted to 0.1 ohm.

A precaution is necessary in making this test, to avoid a certain ambiguity which may present itself. The test, taken by itself, does not determine whether the angle 2β of the line impedance Z_L is positive or negative. Thus, if the voltage triangle OAG is inverted, as drawn in heavy lines on Fig. 32, then the impedance angle is positive as given in Fig. 33; but if the voltage triangle is erect, as drawn at $OA'G$, in broken lines, in Fig. 32, then the impedance angle is negative, as given in Fig. 34. In many cases the known conditions of the line determine which of these two conditions exist. In some cases, however, it may not be easy to decide in advance, which way the e.m.f. triangle will lie. In these cases an additional known reactance may be added to the line, or to the resistance R, and the test repeated. The disturbance set up in the triangle by the introduction of the new reactance will have a visible direction, and will enable a decision to be arrived at as to the aspect of the original triangle.

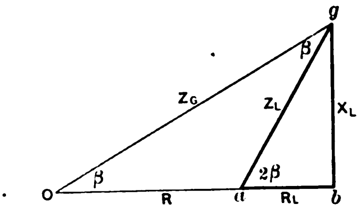

Fig. 33.—Process for Measuring Line Impedance.

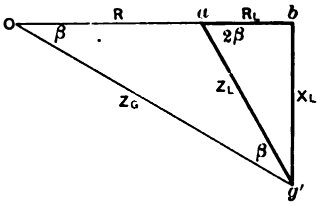

Fig. 34.—Process for Measuring Line Impedance.

When an alternating-current potentiometer is available, the measurement of line impedance is made very easily, and without any ambiguity as to phase-angle sign, by observing both the impressed voltage and the sending-end current, as for example the values recorded in Table IV, at the heads of columns V and VIII. The ratio of these two values is, of course, the required vector sending-end impedance in ohms.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 25, 1912.

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(*Subject to final revision for the Transactions.*)

THE ELECTRIC STRENGTH OF AIR—III.

BY J. B. WHITEHEAD

The two earlier papers of this series discussed more particularly the conditions governing the start of the high voltage corona. This line of investigation is continued to some extent in the present paper. In addition some interesting observations of the properties of the full-formed corona itself are recorded.

The work described in these papers has as its principal object a further knowledge of the physical laws underlying the widely diverse manifestations of the break down of the air under electric stress. Several results described in the earlier papers, *e.g.*, the influence of moisture, of atmospheric pressure, and of stranding the conductor, have had a direct practical bearing. For the most part, however, the results are of only indirect value to engineers, since they are concerned rather with the ultimate nature of the corona. For this reason and also because in Institute discussions of corona phenomena some indifference has been expressed to the introduction of the language of present accepted theories of gaseous conduction, the results of the present paper are offered to the Institute with some diffidence. The writer is encouraged, however, by a conviction that the electrical engineer can no longer afford to rest content with observed facts and laws, or as one has expressed it to be " satisfied with the volt-ampere characteristic, " leaving investigation and explanation to the physicist. However true this may be for other branches of engineering, the position is not tenable for us. For in every direction we are face to face with unexplained facts and unexplored fields of investigation. And we have at our disposal apparatus and a range of variation of the quantities involved which are usually denied the physicist by his lack of engineering training. We can perform lasting service by extending the limits within which existing theories have been tested and by exploring phenomena which seem to fall under no theory. Thus the investigations described in these papers have been undertaken partly under the attraction inherent in journeys into new country, but also in the certainty that the laws of corona formation can be obtained only by controlling all the attendant conditions. A more intimate study is necessary than is possible on transmission lines in the open, or in other instances where the range of observation is restricted to one set of conditions containing many elements.

The present experiments may be divided into three classes. The first is a study of the nature of the conductivity or ionization of the air in the neighborhood of the corona. The second, the determination of the diameter of the corona for several particular cases. The third, an investigation of the influence of the subdivision of a conductor on the corona forming voltage.

THE IONIZATION DUE TO THE CORONA

In the experiments with cylinder and central wire described in the earlier papers it will be recalled that the conductivity imparted by the corona to the air, in discharging an electroscope, afforded an accurate means of observing the initial breakdown of the air. It was noticed that the electroscope acted equally well as an indicator of the first presence of corona whether charged positively or negatively. With increasing alternating voltage and corona volume there was some indication that the discharge was more rapid when the electroscope was charged negatively. The time of complete discharge is so short, however, when the voltage is pushed even slightly above the critical value, that the electroscope becomes unsuitable for studying this peculiarity. A less sensitive instrument is necessary. In the arrangement of apparatus shown in Fig. 1 the wire *A* on which the corona forms, lies along the axis of a woven wire cylinder *B*, 17.13 cm. in diameter and 120 cm. long. The wire of the cylinder was No. 19 B.&.S. guage and the square mesh opening 0.8 cm. on a side. No appreciable alteration of the symmetrical field inside the cylinder is caused by the openings. Corona voltages measured with this cylinder agree with those taken with the same wires in solid wall cylinders. An outer sheet metal cylinder *C*, 17.8 cm. in diameter and 50 cm. long was placed outside the wire mesh cylinder *B*, and suspended from two sulphur insulators, *D*. This cylinder therefore formed a large insulated electrode for collecting the charge which originating as ions in the corona, escapes under the velocity of the electric field through the openings in the wire cylinder. Screens *S S* restrict the charge collected to that originating from a constant length of wire. The wire cylinder was connected to ground throughout the experiments. The outer cylinder was connected through a D'Arsonval galvanometer giving a deflection of one mm. at 2×10^{-7} amperes, to either the positive or negative terminal of a variable source of continuous potential, the other terminal being connected to ground. When no field is applied between *B* and *C* any charge that reaches *C* is due to the velocity acquired by the ions or charged particles of air while inside the cylinder *B* and so under the influence of the electric field between *A* and *B*. When a continuous potential difference is applied between *B* and *C*, and when a corona exists on the wire *A*, the resulting charge which flows away from *C* is of sufficient magnitude to give large deflections in galvanometers of moderate sensibility. Evidences of ionization or conductivity may be detected by the electroscope at distances of 30 cm. or more when the cylinder *C* is removed, but in order to bring the current corresponding to the continuous rate at which the charge reaches *C*, within range of ordinary galvanometers, the separation between *C* and *B* should be small. Obviously when *C* is charged positively it will collect negative ions and vice versa, and the greater the potential to which *C* is raised, positive or negative, the greater proportion of ions which, escaping through *B*, will reach *C*.

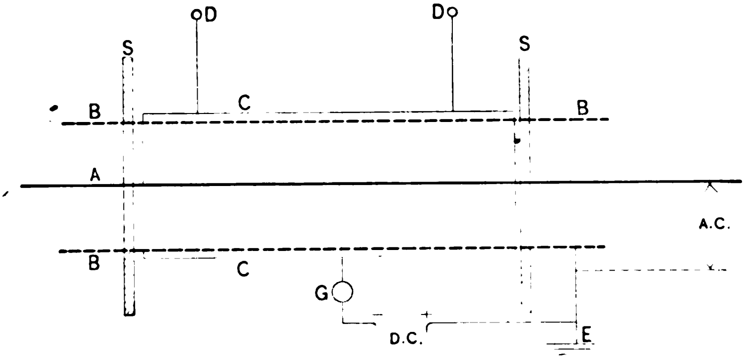

FIG. 1.—POSITIVE AND NEGATIVE IONIZATION OF THE CORONA.

The first experiments were made with a 0.152-cm. polished copper wire. The corona started on this wire at about 63 volts on the primary of the step-up transformer of ratio 1 : 250. Voltage control was obtained with an induction regulator. The wave shape was closely sinusoidal. As the study is purely qualitative the observations are omitted and the results are plotted in curves with the quantities as read on the several instruments as coordinates. Fig. 2 shows three curves plotted between galvanometer deflection and values of continuous negative potential up to 120 volts applied to the outer cylinder *C*. The three curves were taken with 80, 100 and 120 volts respectively, on the transformer primary. The curves show by their intersection with the axis of zero continuous potential the interesting fact that at low alternating voltages, that is in the neighborhood of the start of corona, an excess of positive ions reaches the opposite conductor, whereas, with increasing alterna-

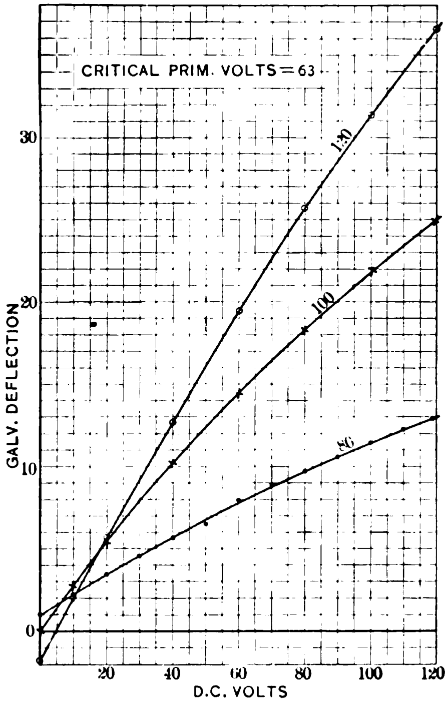

FIG. 2.—POSITIVE IONIZATION FROM CORONA.

ting voltage the sign of this excess changes to negative. Thus with no voltage between the outer cylinder and ground and with alternating voltage only slightly above that at which corona starts, there is a small but definite positive charge collected on *C*; with increasing alternating voltage the sign of this charge changes to negative. The values of these charges are small, as a low value of continuous negative potential between *B* and *C* masks the difference except in so far as indicated by the inter-

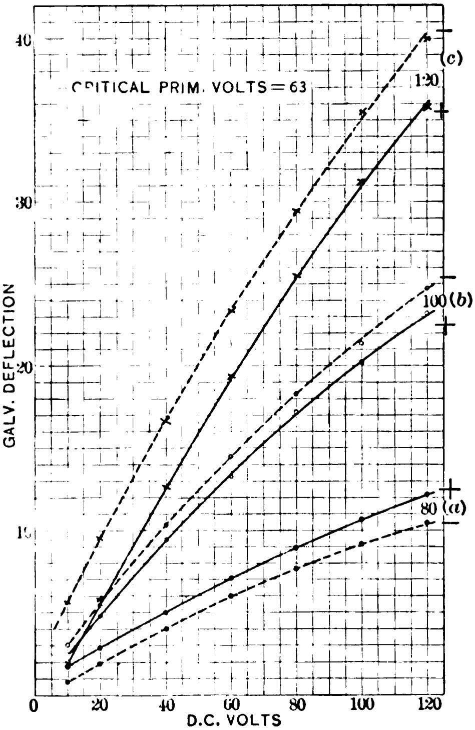

Fig 3.—Positive and Negative Ionization from Corona.

sections of the curves. The curves also show that at 120 volts between *B* and *C* the galvanometer deflections are still increasing rapidly with the voltage, indicating that only a fraction of the total conductivity or ionization generated by the corona is collected by *C*.

The curves of Fig. 3 show for the same alternating voltages the results with *C* at different values of positive and negative potential with reference to *B*. The solid lines indicate positive charge, the dashed lines the negative charge collected on *C*. The curves *a* for 80 volts (primary) show that the excess of positive charge at low alternating voltage, shown in Fig. 2 is independent of the potentials of *C*. The curves *b* and *c* show that there is a reversal of sign of the excess charge reaching *C* between 80 and 100 alternating primary volts, and that the excess of negative charge increases with further increasing alternating voltage.

A further series of observations was taken for the values of alternating voltage between 63, the primary voltage at which corona begins, and 120, with *C* at various positive and negative potentials. The curves are similar to those of Fig. 3 and are omitted from that figure in order to avoid confusion. They also show in agreement with the observations described in the first paper of this series that there is no ionization before corona starts. They show further that at 97 volts the curves for positive and negative potentials of *C* coincide, *i.e.*, that the excess of ionization changes sign at this voltage.

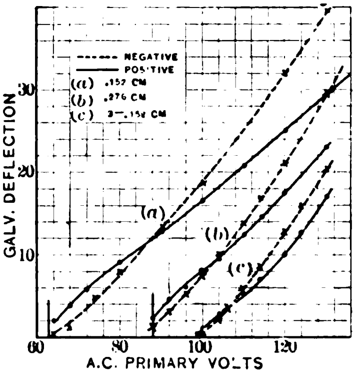

FIG. 4.—IONIZATION FROM CORONA.

The curves of Fig. 4 show, for 0.152-cm. and 0.276-cm. wires, the variation between current received at the electrode *C* and alternating primary voltage up to 130, with *C* maintained at 100 volts continuous potential; solid lines *C* negative, dash lines *C* positive. They show that when corona starts a small though appreciable stream of positive ions immediately reaches the opposite conductor; beginning with this value the intensity of the positive stream increases at first sharply but with decreasing rapidity then approximately linearly with the elevation of alternating voltage. The negative stream appears to begin with zero value at the start of corona but to increase more rapidly than the alternating voltage and therefore crosses the line showing the behavior of the positive stream. The third pair of curves in Fig. 4 is plotted from a series of observations with a central conductor consisting of three 0.152-cm. wires arranged in form of an equilateral triangle 0.62 cm. to a side. These curves will be commented on later in this paper. At present it need only be noted that they have the same characteristics as those for the single wires.

The charge received on *C* and read as current on the galvanometer is an indeterminate portion of the total which would reach the cylinder *B* if there were no openings in it. Consequently the actual current values read on the galvanometer can have no direct bearing on the current passing between *A* and *B*. However if the potential of *C* is maintained at the same value throughout a number of tests on different conductors the curves between galvanometer current and alternating voltage may be used as an approximate method of comparing the relation between voltage and conduction current and therefore power loss for the several conductors. Thus from Fig. 4 it is not unreasonable to conclude that the power loss increases with the voltage in approximately the same relation for each of the three conductors there indicated, since the galvanometer current represents approximately the same proportion of total loss current in each case.

The amount of free ionization in the air has often been suggested as having an influence on the corona forming voltage. The author has already shown several reasons why this cannot be so, among them being the cessation of corona with the decreasing voltage of each half wave, the cessation of corona at the same voltage at which it starts, and the independence of the corona voltage of the ionization about the wire, set up by Röntgen rays. A simple experiment bearing further on this question was performed as follows:

A clean copper wire 0.157 cm. in diameter centered in a 15.2-cm. tube started corona at 58.5 primary volts. This wire was then enclosed successively in thin paper tubes of 2.54-cm., 1.27-cm., and 0.95-cm. diameter. These tubes were slightly longer than the outer cylinder and were insulated and held accurately concentric by means of three silk threads at each end. The tubes were made of tracing paper cut in long strips and spiralled so that when suspended horizontally from the ends there was no observable sag at the middle point. Ions in the region outside these tubes would therefore be prevented from reaching the wire, and if these ions have any influence on the corona voltage we should expect an elevation of this voltage when the wire is screened as above. No change in the corona voltage was observed when the largest tube was in place. In the case of the smaller tubes the corona voltage was lower by 1.5 to 2 volts than when the tubes were not inserted. In this experiment the number of ions in the neighborhood of the wire is lower when the paper tube is in place. Since the tube prevents the ions moving under the influence of the electric field, from reaching the central wire. Consequently we should expect an elevation instead of a lowering of voltage, if the presence of ionization facilitates the formation of corona. The lowering actually observed is probably accounted for by the increased gradient near the wire due to the presence of the thin layer of paper of higher specific inductive capacity than the air. It may be concluded from the experiment that the ionization in the air at a distance from the wire has no influence on the corona forming voltage.

The properties of the ionization emanating from the central wire were also investigated further by a return to the apparatus with solid outer cylinder 18.6 cm. in diameter. A small slit cut in this cylinder was placed opposite a like opening in a large closed box as shown in Fig. 5. An insulated electrode connected with the electroscope could be shifted to various positions in the box. It was found that the electroscope was discharged slowly when the electrode was placed anywhere in the box but far more rapidly when the electrode is located on the line passing through the corona and the opening in the box. The rate of discharge falls off as the electrode is moved away from the opening but may readily be detected at 30 cm. or more.

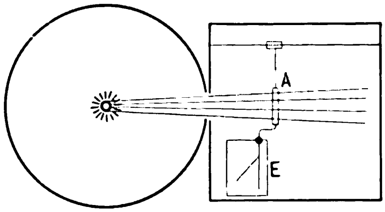

Fig. 5.—Nature of the Ionization of the Corona.

Glass or the thinnest tissue paper placed over the opening completely screens the electroscope from any influence of the ionization. Further if a screen of paper is suspended by threads in front of the opening it is blown away with increasing force as the voltage is raised above that at which corona starts. Below this voltage there is no effect on this paper screen.

The above results show that there is a distinct motion of air away from the corona. That this air carries both positive and negative charges. That it tends to move in straight lines, but that it diffuses or scatters in all directions away from the central beam. Any material obstacle will completely stop this motion. These facts are in accord with the ionization theory and the phenomena may be identified in all respects with the well-known properties of gaseous conduction. Some further discussion of the results will be given at the end of the paper.

DIAMETER OF THE CORONA

Visual Method. When formed on a perfectly smooth clean wire, the corona presents a uniform appearance. While the boundary is not sharply marked, from a short distance there is quite a suggestion of a uniform diameter. The slightest surface imperfections however are indicated by variations in color and diameter of the corona. On small wires the core of the corona has the pink tinge characteristic of other forms of electric discharge in air, shading off to violet of lessening intensity towards the boundary. On larger wires the region at the surface of the wire does not appear so bright or dense, but there is a constant play of intermittent thread-like sparks from the wire toward the boundary. There is quite a suggestion of transparency. Notwithstanding the gradual shading off in intensity toward the outer regions, the uniform corona gives a distinct impression of a definite diameter. It may be conveniently studied by the central wire and cylinder method by cutting small slots in the cylinder, or by making the cylinder of wire mesh. With the cylinder connected to earth close inspection is possible.

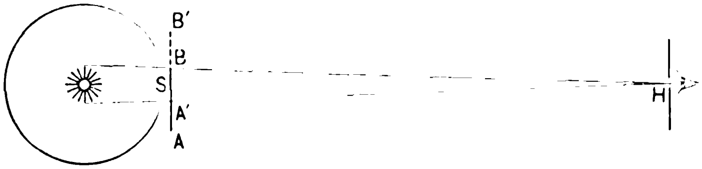

FIG. 6.—METHOD OF MEASURING THE DIAMETER OF THE VISIBLE CORONA.

A number of measurements of the diameter of the visible corona were made following the direct optical method described in the first paper. The method is indicated in Fig. 6. A vertical slit *S*, 2 cm. wide was cut in the horizontal outer cylinder of 18.6 cm. diameter. A screen wide enough (1.9 cm.) to obscure the corona was attached to a cathetometer permitting its motion up or down in a plane close to the slit. With the eye at a pinhole *H*, the screen was gradually moved upward from below until the top edge of the corona disappeared as in the position *AB*, then the screen was moved downward from above to the position *A′ B′* in which the lower edge was completely obscured. The width of the screen was 1.9 cm., the distance from the wire to the screen 9.8 cm. and from screen to eye 785 cm. These data permit ready calculation of the apparent diameter of the corona. The experiments were made with a 0.233-cm. diameter wire centered in an 18.6-cm. cylinder and the corona started at 23,250 effective volts. A number of determinations of diameter were made at several voltages. Only those at 32,500 volts will be given, as read on different days.

TABLE I. VISIBLE DIAMETER OF CORONA 0.233-CM. WIRE IN 18.6-CM. CYLINDER.

Top	Bottom	Top	Bottom	Top	Bottom
70.85	72.16	70.88	72.27	70.94	72.2
70.88	72.18	70.88	72.22	70.94	72.22
70.85	72.18			70.95	72.16
70.86	72.18			70.92	72.18

Successive settings on any one occasion show a very satisfying constancy, but the results on different days vary somewhat. Thus the mean differences of the above sets are 1.32, 1.38 and 1.25; these give a mean value of 1.31 with a maximum variation of 5 per cent. The corresponding diameter of the corona is about 6.7 mm. From the rough experiment described in the first paper it appeared that the diameter of the corona was very nearly that of the solid conductor which would just begin to form corona at the voltage giving the corona whose diameter was measured. The present experiments which were more numerous and made with greater care indicate that this approximation is not so close as suggested by the earlier result. The critical voltage of a conductor 0.67 cm. in diameter placed in an 18.6-cm. cylinder is about 37,000, whereas the voltage of the corona 0.67 cm. in diameter (on a 0.233-cm. wire) was, as stated above 32,500. From this it appears that while the conductivity of the corona is high, there is nevertheless an appreciable loss in it. The experiments on the visual measurement of the diameter were not carried further. With practice and care quite consistent results may be obtained, but the following photographic results indicate that the visible corona probably does not mark the boundary of the region in which the air is breaking down.

Photographic Method. No extensive attempt to measure the diameter of the corona by photographic methods appears to have been made. Jona mentions the failure of his attempts in his paper before the St. Louis International Electric Congress in 1904. Such methods have properly been regarded with suspicion owing to the want in definiteness of outline, the importance of the time element in the exposures, the ultra-violet content of the corona, etc. The best possibilities of the method do not, however, appear to have been developed. In the present experiments careful cleaning of the wire has resulted in very uniform photographs, which while lacking definite lines of corona boundary nevertheless give the impression that this boundary lies within comparatively narrow limits. They are quite suitable for comparing the diameters corresponding to various voltages.

Two types of lens were used. The first a fine portrait Steinheil of 13 cm. aperture and 30 cm. focus, which gives excellent definition, but which naturally does not transmit the ultra-violet end of the spectrum. The second lens was a Zeiss achromatic of quartz and fluorite, aperture 3 cm., focus 40 cm., and which transmits all wave-lengths down to 0.00018 mm. The corona was exposed through an opening 8 cm. long and 2 cm. wide in the 18.6-cm. cylinder whose interior was coated with lamp black to prevent reflection. Some of the results are shown in Figs. 7 to 12. Fig. 7 shows the influence of time of exposure; *a*, *b*, and *c* are exposures of one, two and three minutes respectively with the glass lens, of the corona formed at 32,500 volts on the 0.233-cm. wire; the critical voltage for the wire is 20,750. The exposures were made in quick succession on the same plate, and all were developed and fixed together. This method was followed with all the exposures which are compared with each other. The exposure *c* has apparently the greatest diameter. On inspection under a glass, however, the plate shows that the limits of *b* and *c* are about the same, although *c* is naturally the denser. For comparative purposes therefore two minute exposures were used. Fig. 8 shows the coronæ on the same wire at 22,500, 27,500 and 32,500 volts respectively with one-minute exposures, and Fig. 9 the same with two-minute exposures. Corrected to actual size the diameters of the coronæ at the three voltages as taken from the two-minute exposures are 5.5 mm., 9.3 mm. and 11.1 mm. respectively. These diameters mark the limit to which the emulsion of the plate is affected, as observed under a strong reading glass. Obviously the values are therefore only approximate. However four independent observations of exposure *c* resulted as follows: 10.9, 11.1, 11.2, 11.2 giving the mean 11.1 mm., and indicating an inaccuracy of only 2 or 3 per cent. By the direct visual method the diameter of the visible corona under the same conditions was 6.7 mm.

A number of exposures were then made with the quartz fluorite lens. Owing to the smaller aperture the exposures were much longer, from 20 to 40 minutes. In order to secure a direct comparison between exposures with and without the ultra-violet content, one half of the plate was screened with a thin piece of clear glass which does not transmit the ultra-violet. Some of the results are shown in Fig. 10 in which the exposures were 20 minutes long; the exposures *a*, *b* and *c* were taken with 32,500 volts on wires of diameters 0.232, 0.316 and 0.399 cm. respectively. The transverse bands of lesser intensity are due to two strips across the opening in the wall of the outer cylinder, to prevent possible distortion of the uniform electric field. The broader portions to the left on each exposure give the effect of the entire visible spectrum with ultra-violet added; the narrower right hand portions show the effect of cutting out the ultra-violet with a piece of ordinary plate glass. The diameters as measured from the plates with the aid of a glass in the manner described above are given in Table II.

TABLE II.

DIAMETERS OF CORONA, WITH AND WITHOUT ULTRA-VIOLET CONTENT.

0.232-cm. wire		0.316-cm. wire		0.399 cm. wire	
Quartz and glass	Quartz alone	Quartz and glass	Quartz alone	Quartz and glass	Quartz alone
12	12.4	12.5	13.3	11.4	13
11.5	12.6	13	14	11.6	13
11.5	12.6	13	14	12	12.8
11.4	13	12.8	14	12	12.8
11.6	12.6	12.8	13.8	11.7	12.9

As stated above all the observations in Table II were taken at 32,500 volts which is well above the critical voltage for the largest wire. It is interesting to note that within the limits of accuracy (about 5 per cent) of the method of measuring the diameters, the coronæ on the above three wires at the same voltage have approximately the same diameter both in the visible

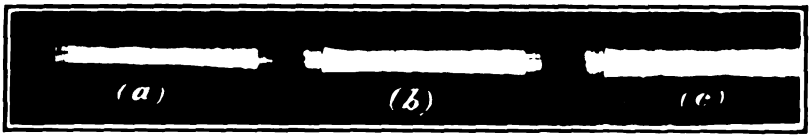

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FIG. 7

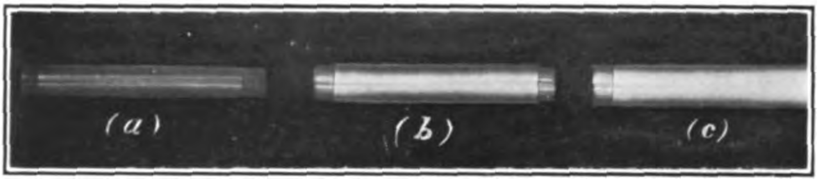

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FIG. 8

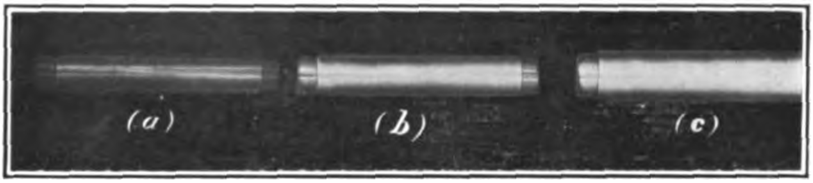

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FIG. 9

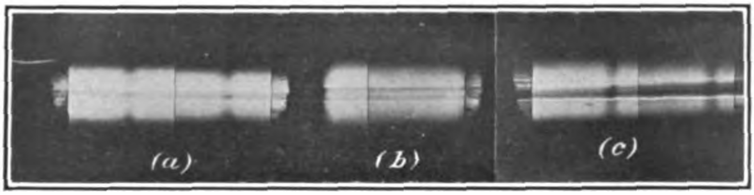

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FIG. 10

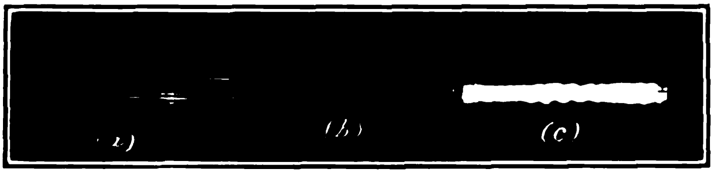

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FIG. 11

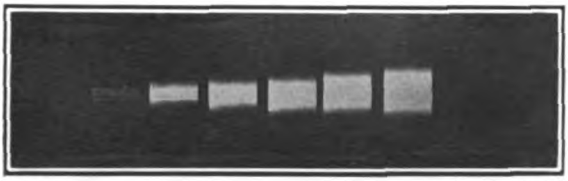

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FIG. 12

and ultra-violet. This fact has also been noted by Jona, who estimated from the appearance at a distance that several wires of different diameters subjected to the same voltage formed coronæ of equal diameter. The diameter for the 0.232-cm. wire taken over 20 minutes is seen to be in fair agreement with that taken over three minutes with the glass lens. It is not probable that there are present any shorter wave lengths than those transmitted by the Ziess lens. The presence of Röntgen rays has been suggested. To test this question a very sensitive plate was wrapped in one thickness of black paper, and placed directly against the opening in the outer cylinder. After 20 minutes exposure the plate was found to be entirely unaffected showing that Röntgen rays if present must be in very small amount and degree of penetrating power.

Fig. 11 shows two observations of interest. The first, *a*, is the corona on the 0.399-cm. wire at a voltage very slightly above the critical or corona starting value. As transmitted through glass the corona shows little more than the outline of the wire. Through the quartz lens, however, without the interposition of glass the corona is seen to have a diameter over twice that of the wire. This is in accord with common observation that the visible corona starts suddenly, and from the beginning appears to have an appreciable thickness. The reproduction of the print from this negative is not very satisfactory, but the plate itself reveals the above fact. The other exposures, *b* and *c*, of Fig. 11 show a curious result for which no explanation has been found. The spiral form of the corona shown was observed and photographed several times with this particular wire. Between observations the wire (a 0.233-cm. steel rod) was removed, carefully polished, and examined for surface peculiarities. Nothing was observable under the microscope, but by reflected light the surface gave evidence of slight circumferential corrugations. Since these corrugations had no spiral they do not appear to be a complete explanation of the several photographs. The depth of the spiral and sharply marked threads are especially interesting in view of the extremely minute variation in the apparently smooth and uniform surface of the wire.

Considering, then, these several methods of estimating the diameter of the corona we find that the visual method gives the smallest value. A photographic determination with the usual type of glass lens gives a diameter larger in the approximate ratio 1 : 1.6. With the ultra-violet down to 0.00018-mm. wave length included, the photographic method gives a further increase over the visible diameter in the ratio 1 : 1.9. The absence of Röntgen radiation suggests that there is little other radiation shorter than that transmitted by the Zeiss lens and therefore that the ultra-violet corona marks the limit of the region in which ionization is taking place.

Fig. 12 shows a series of two-minute exposures with the glass lens of the corona on the 0.233-cm. wire in the 18.6-cm. cylinder at primary voltages, 90, 100, 110, 120, 130 and 140 volts (ratio of transformation 1 : 250). The critical primary voltage was 86. The diameters were measured from the plate under a glass as described above. Corrected so as to include the ultra-violet by the factor 1.18 the diameters are plotted in relation to the primary volts in Fig. 13. Apparently the diameter increases sharply at the critical voltage, then more slowly and finally in a linear relation with the voltage.

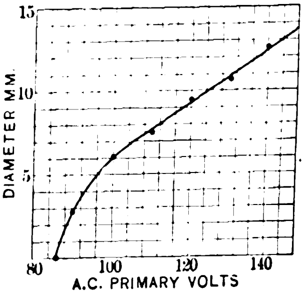

Fig. 13.—Diameter of Corona.
0.233-cm. wire in 18.6-cm. tube.

The Corona Voltage of Subdivided Conductors

One of the most interesting questions in connection with the formation of corona is the explanation of the simple law given in the second paper of this series connecting the critical surface potential gradient and the diameter of the conductor. The ionization theory of gaseous conduction and discharge accounts for so many of the observed phenomena that it is practically universally accepted. So far, however, the theory has not been brought into accord with all the phenomena of corona formation, and indeed some of the observed facts are in direct opposition to the tenets of this theory. As regards the influence of temperature and pressure observation and theory appear to be in accord. But the influence of the curvature of the conductor, and the apparent absence in corona formation of an influence of the amount of free ionization remain to be explained. As regards the former various suggestions have been made, as for example, a condensed layer of air near the conductor, the concentration of ions under the strong electric field at the surface, etc. as suggested by the author. As between these two suggestions it should be possible to draw a conclusion by the combination of a circular conductor and a field which is not symmetrical about it, provided the surface potential gradient corresponding to a given voltage can be calculated. For if a condensation layer is involved the critical intensity should be the same in the symmetrical and unsymmetrical fields, while if the density or motion of existing ionization is involved a difference in the critical intensities in the symmetrical and unsymmetrical cases would be probable.

The following experiments were undertaken partly with the aim to distinguish between the two ideas above noted. They consist in observations of the corona voltage of three or more wires in parallel arranged at the corners of equilateral figures, and symmetrically placed on the axis of the surrounding cylinder. It was also realized that in this arrangement the equipotential surfaces, proceeding outward from the central wires, would tend to approach the circular form; or in other words that the potential gradient near the surface of one of the component wires corresponding to a given voltage, would be less with the multiple wire arrangement than with a single wire, owing to the influence of the other wires. Consequently several wires in parallel might require a higher voltage for breakdown than a single wire of section equal to that of all the others. The results of the experiments do not shed much light on the cause of higher critical intensities of small wires, owing to the difficulty of calculating the intensity corresponding to the various voltages observed. They indicate, however, that the air near a wire of circular section may require different values of electric intensity for breakdown. They also show an interesting relation between the critical voltage of a single conductor and that of three and four wires of equal aggregate cross section, arranged in a symmetrical figure and connected in multiple.

The first experiments were made with three 0.152-cm. wires in the 17.2-cm. diameter wire mesh cylinder already mentioned. The wires were arranged at the corners of equilateral triangles with circumscribing circles of radii between 0.47 and 1.58 cm. The galvanometer was used as detecting instrument, the connections being shown in Fig. 1. The maximum primary voltage which corona started was 105.6 for the triangle of radius 0.7-cm. The corona voltage of a single 0.274 cm. wire which is approximately equal in section to the three wires used was 91.6 volts. Thus the corona voltage for the three wires was 15.3

per cent higher than that of the single wire of equal cross section. The ionization experiments in the first section of the paper and the curves of Fig. 4 show that the leakage loss due to the ionization resulting from the corona varies in the same way with increasing voltage for three wires as with one wire.

Considerable difficulty was found in the foregoing experiments in maintaining uniform spacing and tension of the three wires. Further experiments were therefore arranged, using three 0.238-cm. steel rods hung vertically and each provided with individual screw thread adjustment of tension. They were placed in a 29.2-cm. cylinder in triangles of radii from 0.3 to 2.54 cm. In these experiments the visible corona was used as detector of the critical voltage. The voltage was obtained from a 100,000-volt 10-kw. transformer fed from a generator excited from a storage battery and driven by a direct connected motor. The voltage was read at the terminals of a low tension secondary coil. The ratio of transformation was 1 to 833.36; the method of observation, carried out in a completely darkened room, was to gradually increase the current in the generator field until corona appeared as viewed through a small opening in the wall of the outer cylinder. The voltage was read simultaneously by a separate observer. The observations are given as taken in Table III. In the fourth column the mean value is corrected to 21 deg. cent. and 760 mm. pressure. The table also includes the results of contemporaneous observations on single wires of 0.238, 0.397, and 0.476 cm. diameter. The nearest of these to a cross section equivalent to that of three 0.238-cm. wires is

TABLE III.

CORONA VOLTAGES OF THREE 0.238-CM. WIRES IN PARALLEL, PLACED AT APEXES OF EQUILATERAL TRIANGLES

Conductor	Radius of triangle cm.	Volts			factor	Max. secy Intensity
		Observed	Corrected	Max. secy.		
0.238 cm.	——	26.7	25.8	33,300	—	59,800
0.397 “	——	36.1	35.1	45,300	—	53,270
0.412 “	——	(Calculated)	35.7	46,200	—	52,860
0.476 “	——	40.7	39.6	51,100	—	51,400
3-0.238	0.317	41.1, 40.6, 41.1	39.6	51,200	1.38	70,700
“	0.634	42.7, 42.7, 42.6	41.5	53,700	1.21	65,500
“	0.952	42.1, 42.2, 41.6	40.7	52,600	1.17	61,500
“	1.27	41.7, 41.7, 41.4	40.5	52,500	1.11	58,300
“	1.58	40.9, 41 , 40.5	39.5	51,100	1.16	59,400
“	1.90	39 , 39.7, 38.9	38.2	49,400	1.22	60,600
“	2.54	38 , 38 , 37.5	37	47,850	1.3	62,500

0.397; correcting the observation for the 0.397-cm. wire to the true cross section indicates a value of critical volts 46,250. The observed critical voltage for the three 0.238-cm. wires has a maximum value for the triangle 0.63 cm. in radius. This value was 53,700, that is, an increase of 16.3 per cent over that of the single wire of equal aggregate cross section.

The observations of Table III, together with those of another series taken with the same wires are plotted in Fig. 14 between test coil volts and radius of triangle. While the observations for any one arrangement were found to be very uniform, it will be noticed that the points do not fall at all regularly on a continuous curve. A large number of repetitions for different sizes of triangles failed to eliminate this trouble. The explanation was found in the impossibility of adjusting the wires to uniform tension throughout the different sizes of triangle. It was found that the electrostatic repulsion between the wires caused them to spread apart in varying degrees. A number of light brass separators of triangular shape were used but they only lessened the trouble slightly. Each series of observations, however, resulted in showing that the critical voltage for three wires was invariably in the neighborhood of 16 per cent higher than that for the single wire of equal aggregate section and this maximum elevation occurred when the wires were at the corners of a triangle lying within a circle of 0.63 cm. radius as measured at the ends. This means that the wires were separated by approximately five diameters. The electrostatic spreading could not be determined but the actual separation was somewhat greater than stated.

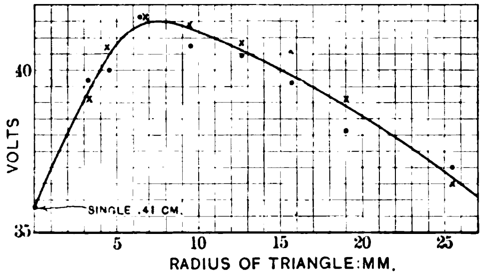

FIG. 14.—CORONA VOLTAGE.
Three 0.238-cm. diameter wires in parallel.

A series of experiments was also conducted on four 0.238-cm.

rods arranged in the figure of a square, the sizes of these squares being such as to just lie within circles of 0.635 cm. to 10.6 cm. radius, otherwise the apparatus, method of operation, etc., was the same as that described for the three wires. Separators were also used to reduce the electrostatic spreading. The observations are given in Table IV, showing the variation of critical test coil volts with the diameter of a circle passing through the centers of the four wires. The critical voltage for a single 0.467-cm. wire which is equal to four 0.238 cm. wires is also given. These results indicate that the maximum corona voltage for the four wires occurs when they are arranged on a 3.3-cm. circle and that the approximate elevation of voltage for four wires above that of a single wire of equal section is 20 per cent. It will be noticed that the diameter of the circle giving maximum voltage is much greater for four wires than for three.

The last three columns of Table III give, first, the secondary voltage, maximum value corrected for wave form; second, the factors which multiply the maximum secondary voltage in order to give the maximum surface intensity on each wire and, in the last column, the values of this maximum surface intensity. The correction for wave form was made by referring the observations on three sizes of single wire to formula **1** of the second paper of this series, connecting maximum critical surface intensity with the diameter of the wire. The method of calculating the factor given in the next to the last column will be described later in the paper. It will be noted that the last column indicates that the maximum intensity occurring on the surface of the wires decreases from 70,700 to a minimum in the neighborhood of 59,000 and then apparently begins to increase again. The critical surface intensity for a single wire of the same size as the three used is 59,500. It is apparent, therefore, from these results that the critical surface intensity is not necessarily a constant for a given size wire but depends in large measure on the configuration of the field, due to neighboring conductors.

TABLE IV.
CORONA VOLTAGES OF FOUR 0.238-CM. WIRES IN PARALLEL AND PLACED ON CORNERS OF SQUARES.

Radius of circle cm.	0.63	1.27	1.90	2.54	3.17	3.81	5.08
Volts	85.2	94.1	94.9	94.6	95	92	90.5
Critical volts for single 0.476-cm. wires = 78.8							

It is further evident that by sub-dividing the total cross section of a given conductor into a number of smaller conductors and arranging them suitably, the critical voltage may be raised in considerable amount. The simplest arrangement, that of three wires, results in an elevation 16 per cent. It is open to some question whether it would be possible to take advantage of these facts in actual transmission lines. It is quite probable, however, that the principle would be available in the case of solid and liquid dielectrics. It is also worth noting that a similar sub-division of the total cross section of a transmission conductor has been suggested for the purpose of adjusting to best advantage the ratio of inductance and capacity of transmission lines.*

DISCUSSION

It is of interest to speculate upon the explanation of the excess positive charge due to corona near its start, and the change of this excess to the negative sign with higher values of alternating voltage. It has been noted that there is a difference in the corona for positive and negative continuous voltages and it is therefore not impossible that the corona may start at a somewhat different voltage on each half of the alternating wave. If we assume as is practically certain, that the initial ionization is due to the collision between a molecule and a negative electron, we have a very probable explanation of the observed results. The electron must attain its critical velocity when moving inward toward the wire, since the intensity of the field increases in that direction. This being so the corona would start when the wire is positive; therefore the positive ions would be repelled. It is only necessary to assume a slight difference in the critical voltage for the two halves of the wave to explain the first appearance of the positive ion. Indeed the fact that the negative electron is invariably the first ionizing agent and the additional fact that field increases towards the wire makes it certain that the first corona appears when the wire is positive.

For increasing value of voltage, the corona forms on both half waves and the charge reaching the outer cylinder is the resultant due to both half waves. Negative ions move faster than positive hence, when both half waves are active, there will be an increasing excess of negative charge appearing. The relative behavior of the positive and negative excess may be seen from the curves of Fig. 4.

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*P. H. Thomas, TRANSACTIONS A.I.E.E. Vol. XXVIII, p. 641.

Referring to the experiments with small paper tubes surrounding the wires, the failure of these tubes to cause an elevation of the critical voltage apparently indicates that this voltage is to a large extent independent of the number of free ions in the atmosphere. It also shows that the suggestion that ions may bank up in the neighborhood of the wire, thus lowering the surface intensity, is hardly tenable as an explanation of the law expressed by formula (**1**) of the second paper, connecting critical surface intensity with diameter of the wire. In order to test this suggestion further, a calculation has been made of the lowering of the surface intensity corresponding to a given voltage, caused by the attraction to the surface of all of the ions which commonly exist in the atmosphere.

The greatest distance from which an ion will reach one wire subjected to alternating voltage may be conveniently investigated for the case of two parallel wires of radius r and distance D apart. If V is the instantaneous voltage and v is the specific velocity of an ion, that is, its velocity in cm. per sec. per volt per cm., we have,

$$\text{Gradient at distance } r = \frac{V}{2\,r \log \frac{d}{a}}$$

$$\text{velocity, } v, \text{ at } r \text{ at any instant } t = \frac{v\,V_0 \cos n\,t}{2r \log \frac{d}{a}}$$

$$\text{In time } dt, \text{ distance traversed, } dr = \frac{v\,V_0 \cos nt\,dt}{2r \log \frac{d}{a}}$$

$$\therefore\ 2\,r\,dr = A \cos nt\,dt;\ \text{where } A = \frac{v\,V_0}{\log \frac{d}{a}}$$

$$\therefore\ r^2 = \frac{A}{n} \sin nt + C$$

$$\text{Now } v = o \text{ when } V = O, \text{ and } nt = -\frac{\pi}{2}$$

$$\therefore\ c = \frac{v\,V_0}{n \log \frac{d}{a}} + a^2$$

$$\therefore\ r^2 = \frac{v\,V_0 \sin nt}{n \log \frac{d}{a}} + \frac{v\,V_0}{n \log \frac{d}{a}} + a^2$$

Thus r has its greatest value when $nt = \frac{\pi}{2}$

and is given by $r^2 = \dfrac{2v\,V_0}{n \log \dfrac{d}{a}} + a^2$

From a set of experiments by Peek and Steinmetz in which a was 0.538 cm. and d was 304.8 cm., the visible corona voltage was found to be 157 kilovolts at a frequency of 60 cycles per sec. Taking the value of v, the velocity of the ions, at 1.5 cm. per sec. per volt per cm., the value of r^2 is found to be 276. This means that, under the conditions of the observation, at the time the corona started every ion within a distance of 16 cm. from the wire would be drawn to the surface of the wire between the zero and maximum values of any half wave. Under normal conditions there are about 1000 ions to every cubic cm. of air, the range of variation being to about four times this number. The charge on each of these ions is 4.6×10^{-10}. With these figures in mind the charge per unit of surface resulting from the attraction of these ions to the surface may be calculated and the value of this charge is found to be 4×10^{4} c.g.s. electrostatic units per unit of length. From this the value of the surface electric intensity due to this accumulated charge is found to be only from 0.5 to 2 volts per cm. or entirely negligible as compared with critical corona forming intensity. We may conclude therefore that the attraction of the ions ordinarily existing in the atmosphere to the surface of the wire is not the explanation of the elevation of the critical intensity observed with smaller wires.

Referring again to Table III it has been already stated that the last column gives the values of the maximum critical surface intensity occurring on each of the three wires for different sizes of triangular figure. These values have been obtained by multiplying the maximum value of the critical voltage by the factors given in the next to the last column, and these factors have been deduced for an exact case to which the arrangement of three circular wires only approximates. The fact that the results show that the air breaks down at different values of electric intensity for a single size of wire is important in the indication it carries of the nature of the factors governing the break down. It is therefore necessary to examine the process by which the multiplying factors have been derived, and the degree of approximation of the values of the last column of Table III to those actually obtaining. To do this it is necessary to examine the distribution of potential between the three circular wires and the outer circular cylinder. It is probable that an exact solution of this problem has even been attempted, but a close approximation may be had by considering the potential due to three infinitely thin filaments located at the apexes of an equilateral triangle, each filament having the same and similar charge per unit of length. This case has been discussed very clearly and completely by Alexander Russell.* He shows that the equation of an equipotential surface due to the charges on the three filaments may be expressed by,

$$r^6 - 2a^3r^3 \cos 3\theta + a^6 = r_1^2 \; r_2^2 \; r_2^2 = A^6 \qquad (1)$$

where r is the distance $O\,P$ from the center of the equilateral triangle to a point on the equipotential surface (see Fig. 15); θ is the angle which $O\,P$ makes with a line passing through O and one of the angular points of the triangle; a is the radius of the circle circumscribing the triangle; r_1, r_2 and r_3 are the distances of P from the three angular points; and A is a constant which contains the value of the potential of the particular surface in question. When A is zero the curves reduce to the three points α, β, γ. For small values of A the curves are ovals which approximate circles enclosing the three points. For large values of A the equation represents a single curve enclosing α, β and γ and which for increasing A approaches a circle.

By Greene's Theorem we can replace any conductor by another surrounding it provided that the surface of the outer conductor is an equipotential surface of the system of distribution. Consequently if we replace the three filaments by ovals coinciding with the nearer equipotential surfaces, and replace any one of the outlying continuous surfaces by a conductor, we have a system which approximates three cylindrical conductors in triangular arrangement at the center of an outer cylinder. If the approximation is sufficiently close we may use the relation of the exact case for calculating the potential gradients at the interesting points of the arrangement using the cylindrical conductors and outer cylinder. Russell does not discuss this question further than to note that when the longest radius of an outer surface is equal to $2a$ the variation from true circular form is less than 5 per cent. In the experiments described above the greatest value of a was only one-sixth the radius of the outer cylinder. It may be shown by simple calculation that in the exact case the surface which passes through the point $r = 6a, \theta = 0$, has $6a$ and $5.99a$ as its maximum and minimum values of r. Consequently the error in the use of a true cylinder for the outer conductor is only a small fraction of one per cent, *i.e.*, negligible.

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*Russell, "Alternating Currents." Vol. 1, chapter IV.

The maximum values of potential gradient in the exact case as well as in the case of three cylinders will occur at the extreme outer points of the three conductors, *i.e.*, at the outer intersection of a line drawn through the center of the triangle and the center of a wire section, with the circle or oval representing this section. The value of this potential gradient will vary with the length of sides of the triangle, that is with the separation of the three wires. For the exact case the gradient at these points may be calculated as follows: The conductors are equipotential surfaces; if their potential be v_1, the surfaces are given by

$$v_1 = c - \frac{q}{3} \log (r^6 - 2a^3r^3 \cos 3\,\theta + a^6) \qquad (2)$$

in which C is a constant and $\frac{q}{3}$ is the charge on each of the three wires. per unit of length. The value of $\frac{q}{3}$ corresponding to a potential v_1 of the three inner conductors and v_2 of an outer enclosing cylindrical conductor of radius R is given by

$$\frac{q}{3} = \frac{v_1 - v_2}{2 \log \dfrac{R^3 - a^3}{a^3 - b^3}}$$

since the capacity* per unit length between the three wires in parallel and the outer cylinder is

$$K = \frac{3}{2 \log \dfrac{R^3 - a^3}{a^3 - b^3}}$$

At the point C, $\theta = 0$ and r is perpendicular to all the equipotential surfaces. Therefore the maximum normal surface potential gradient is given by

$$\frac{\partial v_1}{\partial r} = \frac{q}{3} \frac{6\,r^5 - 6a^3\,r^2 \cos 3\,\theta}{r^6 - 2a^3\,r^3 \cos 3\,\theta + a^6} \qquad (3)$$

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*Russell, loc. cit.

In the experiments the outer cylinder was connected to earth. Thus the maximum normal surface intensity in volts per centimeter, which occurs at the points $r = c$, $\theta = 0$ is given by:

$$X = \frac{d\,v}{d\,r} = \frac{V}{2 \log \dfrac{R^3 - a^3}{a^3 - b^3}} \cdot \frac{6c^5 - 6a^3\,c^2}{c - 2a^3\,c^3 + a^6} \qquad (4)$$

in which V is the maximum value of the voltage between the outer cylinder and the three wires.

All of the above relations are deduced for the exact case in which the three inner conductors have their cross sections of the oval shape shown in Fig. 15. Since the experiments were made with round conductors it is necessary to consider how closely the intensity as calculated by formula (4) will represent that occurring in the experiments. The nearest approximation to the exact case is that of round conductors which exactly enclose the ovals and which therefore have the diameter c-b. A comparison of the radius of curvature of the oval P at the points C, and the angle $2\,\theta$ subtended at the center of the triangle by the two tangents to the oval, with the corresponding quantities for the circle will give an idea of the degree of approximation. Both these quantities obviously are a measure of the rapidity

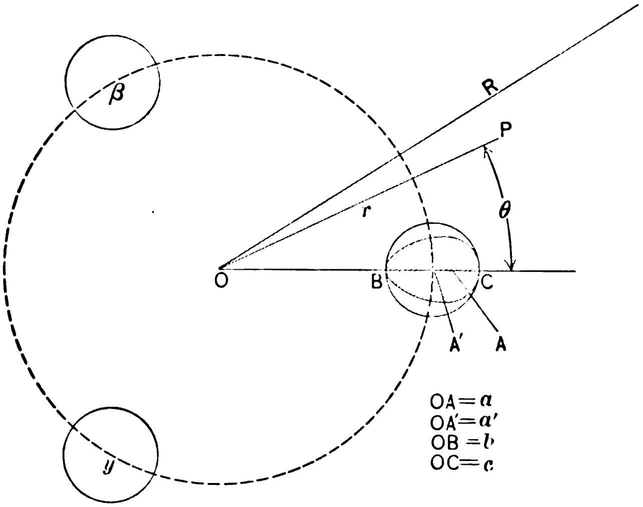

FIG. 15

with which the maximum electric intensity at the extreme outer point will vary with the distance from that point along the surface.

Both the radius of curvature ρ at the point c and the angle $2\,\theta$, between the two tangents to the oval from the center may be calculated from the equations of the curves by well-known methods and are given by

$$\rho = c\,\frac{(c^3 - a^3)}{c^3 + 2a^3} \text{ and } \cos^2 3\,\theta = \frac{b^3\,(2a^3 - b^3)}{a^6}$$

in which a is the a of the formulæ for the exact case and is the distance from the center of the system to each of the three points which are the origin of the true system of equipotential surfaces of which the ovals are a particular example. Thus a is greater than a' the distance from the center of the triangle to the centers of the three circles which take the place of the ovals.

TABLE V.

a' in.	a' cm.	ρ oval cm.	ρ circle cm.	$2\,\theta$ oval	$2\,\theta$ Circle
0.125	0.317	0.943	0.119	37°16′	44°
0.1875	0.476	0.1048	0.119	27°50′	29°
0.25	0.634	0.1096	0.119	20°33′	21°37′
0.375	0.952	0.1158	0.119	14°4′	14°24′
0.5	1.27	0.1162	0.119		
0.625	1.586	0.1165	0.119	8°24′	8°36′
0.75	1.905	0.1176	0.119		
1	2.54	0.1178	0.119		

In Table V values of ρ and 2θ for circular wires of 0.119 cm. radius are compared with those for the true ovals which the circles are assumed to replace. The table shows that the values of both ρ and $2\,\theta$ for the oval and the circle differ by very small amounts when the distance of the center of the wire from the center of the system is greater than 0.63 cm. The values of the multiplying factors of Table III have been calculated from formula (4); the value of a the true center of the exact system of ovals may be readily obtained from the radius a' of the circle on which the centers of round wires lie, and the radius of the wires.

Since the values of ρ and $2\,\theta$ above are greater for the round wires than for the ovals, the values of the surface intensities for a given voltage will be less than in the exact case. Consequently the values given in Table III are too high, particularly for the small triangles. It does not appear, however, that this error is great enough to preclude the conclusion that the critical intensity for the three wire arrangement is much higher for small triangles than that for one of the component wires alone; that with increasing radius of triangle the critical intensity decreases to the value pertaining to the size of the single wires; and that with further increase of separation the critical intensity appears to increase again. It appears from these results that the distribution of the electric intensity is the vital factor in the relation which obtains between the radius of a conductor and the critical electric intensity. Surface layers and condensation layers of high electric strength, often mentioned in vague terms to explain this interesting relation, have not the slightest foundation of experimental evidence. If, however, the theory of secondary ionization is to account for the facts it must show that in the converging field either the mean free path of the electron is shortened or that in some manner the gradient is less than that calculated from the geometrical configuration of the opposite conductors.

The principal result of this paper may be summarized as follows:

1. In the early stages of corona the carriers constituting the leakage current have the positive sign; with increasing voltage negative carriers predominate. Other peculiarities of the ionization arising from the corona are described.

2. The variation of the diameter of the corona with the voltage has been shown by photographic methods.

3. By dividing a circular conductor into three or more equal circular ones symmetrically placed the critical voltage may be raised 16 per cent for division into three, and 20 per cent for division into four wires. In these arrangements the maximum critical intensity for air is shown to have different values even though obtained at the surface of the same wire.

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METALLIC TUNGSTEN AND SOME OF ITS APPLICATIONS

BY W. D. COOLIDGE

Tungsten does not occur as such in nature; but in the form of compounds it is pretty well distributed. The most important ores are sheelite or calcium tungstate and wolframite or iron-manganese tungstate. The principal source of the ore at this time in this country is Boulder County, Colorado.

From the ore it is a simple matter to get the yellow oxide (trioxide) of tungsten. And the trioxide may be reduced in various ways, as with hydrogen, zinc and carbon, to metallic tungsten. The product so obtained is in the shape of a powder ranging in color from gray to black depending upon the fineness of its state of subdivision.

Owing to its very high melting point, it was for a long time impossible to get the pure powdered metal into the form of a dense coherent homogeneous mass. Two Austrians, Messrs. Just and Hanaman[1], working in Vienna, finally succeeded however in producing the pure metal in this condition and in filamentary form, and by using it as an incandescent filament became the inventors of the tungsten lamp.

One of their processes consisted in first mixing the finely divided tungsten powder with a carbonaceous binding agent. The plastic mass so obtained was then extruded through a small orifice. The resulting thread was heated in the absence of air, to carbonize the binder. The fragile body so produced consisted of tungsten powder and carbon and was electrically conducting. If it had been used in this condition it would have been worthless owing to the presence of carbon which lowers the melting point and besides this, slowly distills out in a vacuum, causing a blackening of the lamp globe. But Just and Hanaman found that the carbon could be removed by heating the filament to a high temperature, by passing current through it, in an atmosphere of hydrogen and water vapor. This high temperature treatment not only removes carbon but also causes the filament, under the action of capillary forces, to shrink to a dense homogeneous body.

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[1] U. S. Patent No. 1,018,502.

Various other processes were subsequently devised for making small filaments of pure tungsten. But these were all alike in this, that they started with the finely divided metal or oxide or some other compound of the metal. By the help of some agglomerant, the finely divided material was then worked into a plastic mass. This was then brought into filamentary form by extrusion through a die, and was then raised to a high temperature under such conditions that nothing but pure tungsten remained, the filament sintering under the application of the high temperature to a dense coherent body.

Filaments produced in this way showed the melting point of pure tungsten (about 3000 deg. cent.) And they were very satisfactory as lamp filaments except in one respect—they were weak mechanically. They were, like spun glass, highly elastic but absolutely brittle; that is, they could not, by cold blending, be given the slightest permanent deformation.

In the above mentioned brittle condition, metallic tungsten had, as such, but one single commercial application, namely as a lamp filament. This application was however extremely important—so much so that a vast amount of the most painstaking investigation work was carried out both in this country and abroad in the endeavor to produce a ductile form of tungsten. Without some such enormous commercial interest at stake, it seems extremely doubtful whether the product sought for would ever have been produced. For no one knew but what metallic tungsten, like the silicon of today, was, at room temperature, inherently brittle. And the evidence in support of the theory that it was inherently brittle was almost overwhelming.

At a meeting of the Institute in May, 1910,[2] the author presented a paper telling of the successful reaching of the goal—the production of ductile tungsten. At that time samples of drawn wire were shown and the hope was expressed that within a short time laboratory processes could be brought to a point where the public could profit by the new invention. This development has taken place so rapidly that today the bulk of the world's supply of tungsten lamps is made from drawn wire.

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[2] TRANSACTIONS A.I.E.E. Vol. 29, Part II, pp. 961 to 965.

As has been said above, so long as tungsten was a brittle metal it found but one single technical application. But with the advent of ductile tungsten, the whole situation is changed, and the metal has now, apart from its use as a lamp filament, assumed a very considerable degree of technical importance.

Before proceeding to a discussion of some of the new applications it may be well to summarize here some of the most important properties of wrought tungsten. Most of these data have already been published.[3]

Physical Properties. Wrought tungsten is a bright steel-colored metal having the same density as gold, 19.3. (This varies somewhat with the amount of mechanical working which the specimen has had.)

The strength and pliability both increase with the amount of mechanical working. The fracture may be very coarsely crystalline, or it may resemble that of a very fine grained tool steel or it may be fibrous and silky in appearance, or it may lie anywhere between these extremes, the appearance in each case depending upon the chemical purity and upon the preceding thermal and mechanical treatment. The tensile strengths measured have ranged from 460,000 lb. (208,652 kg.) per sq. in. (6.45 sq. cm.) for a wire 0.005 in. (0.127 mm.) in diameter to 610,000 lb. (276,691 kg.)for a 0.0012-in. (0.0305 mm.) wire.

Tungsten is hardened by working but not by heating and quenching. Similarly tungsten containing carbon is not appreciably affected by quenching. The hardness imparted by working may be entirely removed by carrying the metal to white heat.

The ductility is extreme, as is shown by the fact that wire only 0.0006 in. (0.0152 mm.) in diameter is now produced in large quantity.

Tungsten is non-magnetic.

The electrical resistivity at 25 deg. cent., expressed in microhms per centimeter cube is 6.2 for the hard drawn wire and 5.0 for the same annealed. The corresponding data for annealed copper and annealed platinum are 1.87 and 11.1 respectively.

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[3] C. G. Fink, *Transactions Am. Electrochem. Soc.*, Vol. 17, pp. 229 to 234 (1910).

W. E. Ruder, *Jour. Amer. Chem. Soc.*, April, 1912.

The temperature coefficient of electrical resistivity per degree between 0 deg. and 170 deg. cent. is 0.0051.

Assuming the Franz-Wiedemann law to hold for the relation of heat to electrical conductivity, we may calculate the heat conductivity of annealed wrought tungsten to be 0.37 times that of copper and 2.2 times that of platinum.

The coefficient of heat expansion per degree from 20 deg. to 100 deg. cent., is 336×10^{-8}, which is about 0.26 that of platinum

Chemical Properties. Wrought tungsten does not tarnish upon standing in the air. Upon heating it to a temperature of three or four hundred degrees, however, it oxidizes superficially and turns blue just as steel does. At bright red heat the oxide volatilizes and the metal wastes away more or less rapidly, depending upon the temperature.

It is quite resistant to the action of most acids, being entirely unaffected at room temperature by either dilute or concentrated hydrofluoric, hydrochloric, nitric, and sulphuric acids. With aqua regia at room temperature the action is very slight. At a higher temperature, 110 deg. cent., there is no action in the case of hydrofluoric, concentrated nitric and dilute sulphuric acids, while the action is but slight in the case of dilute and concentrated hydrochloric, concentrated sulphuric, dilute nitric, and aqua regia. There is no action in the case of a mixture of sulphuric and chromic acids, but the metal dissolves rapidly in a mixture of hydrofluoric and nitric acids.

An aqueous solution of caustic potash has no effect on wrought tungsten, but the fused salt does attack the metal slowly.

In aqueous solutions of sodium or potassium carbonate or mixtures of the two, tungsten dissolves slowly, the action being considerably hastened by the addition of potassium nitrate.

ELECTRICAL CONTACTS OF WROUGHT TUNGSTEN

Under the conditions pertaining in many electrical make and break devices, as in magnetos, spark coils, voltage regulators, railway signal relays, telegraph and telephone relays, telegraph sending keys, etc., wrought tungsten has proved to be far superior to platinum or platinum-iridium for the contact points.

This was not in any sense an obvious application, for tungsten is not, like platinum, a difficultly oxidizable metal. It might well have been assumed that under the heat of the minute arcs which form when the contacts are separated, the tungsten would oxidize at the points where arcing has taken place, and that non-conducting layers would thus be formed which would produce a high and variable contact resistance. In fact our first experiments bore out this theory. But subsequent work showed that the difficulty in these early experiments came from the fact that, at the time, we were unable to make a good thermal and electrical joint between the tungsten and the contact carrying members. With the attainment of a good conducting joint, our results changed completely. The contacts no longer rose to the same high temperature and the oxidation decreased to little or nothing. Moreover, in case there was any oxidation, it was to the lower and electrically conducting oxides.

Tungsten contacts wear longer than those of platinum or platinum-iridium. This is doubtless due largely to the lower vapor pressure. At temperatures at which platinum volatilizes badly, tungsten has a very low vapor pressure. Besides this the heat conductivity of tungsten is more than twice that of platinum and as a result, the contact faces do not rise to the same high temperature. (In comparison with platinum-iridium alloys, the ratio of heat conductivities is still more favorable to tungsten). In connection with the life of contacts, another inportant consideration is that of hardness. Tungsten is so hard that it does not batter down at all under the continual hammering which the contacts get in service.

Tungsten contacts show less tendency to stick than do contacts of platinum or platinum-iridium. This is to be attributed in part to the higher melting point of tungsten. There seems to be another factor here, however, for while we are able, by proper manipulation, to securely weld together two pieces of platinum at a temperature considerably below the melting point, it has not as yet been possible, except by actual fusion, to produce anything more than a very weak adhesion between two pieces of tungsten.

One minor and unexpected advantage connected with the use of tungsten contacts consists in the fact that they seem less sensitive to the accidental presence of oil than do platinum contacts.

Allusion has already been made to the difficulty at first experienced in producing satisfactory thermal contact between tungsten and the metal comprising the contact carrying member.

This was due to the fact that tungsten cannot be satisfactorily soldered by any of the ordinary processes. This difficulty has been overcome in the following way: The little disc of tungsten, which is to serve as contact point, is attached by means of copper to the head of an iron tack. Copper does not alloy with tungsten, but, under suitable conditions, it wets it, and then adheres firmly. This gives a joint of high thermal and electrical conductivity between the tungsten and the head of the iron tack. The shank of the tack is then either pressed in, or brazed, or riveted to the contact carrying member.

WROUGHT TUNGSTEN AS TARGET IN A RÖNTGEN (X-RAY) TUBE

This has proved to be, both from the scientific and practical points of view, an exceptionally interesting application.

Until recently platinum has been almost universally regarded as the best target material, and it has so long held undisputed sway in this field that the Röntgen ray worker has come to look upon its limitations as inherent in the Röntgen tube.

With the advent of dense, forged pieces of pure malleable tungsten, the possibilities of the Röntgen tube are greatly extended.

The desiderata in a material to be used as the anticathode or target are the following:

1. High specific gravity.
2. High melting point.
3. High heat conductivity.
4. Low vapor pressure at high temperature.

The reasons why the above qualities are desirable follow readily from a brief consideration of the theory of Röntgen-ray production.

From the concave cathode, electrically charged particles, the electrons, are shot out at high velocity in a direction normal to the surface. The paths of these particles converge and the target is placed at or near the point of strongest convergence, the focus point. When the electron meets an obstruction, as the target, its velocity is reduced, and the denser the target the more rapid is the deceleration. The more rapid the deceleration the greater is the amplitude of the electromagnetic pulse, the Röntgen-ray, sent out. Here then is a need for high specific gravity; that of forged tungsten is but little less than that of platinum.

In modern Röntgen-ray practice, powerful apparatus, running sometimes to a capacity of 10 and even 15 kilowatts, is used to excite the tube. A considerable part (perhaps as much as one-third) of the energy delivered to the tube is transformed into heat at the point where the cathode rays bombard the target. Where platinum is used it has been found necessary, to prevent melting, to place the target beyond the focus of the cathode so as to spread the bombardment over a larger area. As a radiograph is a shadow picture, and as the source of the Röntgen-ray is the bombarded area of the target, this enlarging of that area is clearly an undesirable thing to do, as the larger area will mean more overlapping and less definition in the resulting picture. In this way, the melting point of platinum has been the limiting feature of the Röntgen tube. The capacity of the tube has been increased by water cooling the platinum or by using as a target a large mass of copper having a very thin platinum face. But the limit, although raised by these artifices, has still been the melting point of the platinum.

Tungsten has a much higher melting point (3000 deg. cent. as against 1755 deg. for platinum), and so, even with sharp focusing of the cathode rays on the target, permits the use of more energy than has hitherto been possible; for the high temperature to which it can run enables it to radiate more heat, and its better heat conductivity permits a more rapid flow of heat from the focus spot to the surrounding metal.

Stability of vacuum in a Röntgen tube is of the utmost importance, as the character of the rays is so largely determined by the vacuum. Metal, which under the influence of the high temperature vaporizes from the target, condenses on the glass in finely divided form and absorbs relatively large amounts of gas, thus changing the vacuum. At high temperatures tungsten vaporizes least of all the metals.

Two distinct types of tungsten target are being tried out experimentally in competition with one another.

The first of these consists of a heavy copper block with a disc of wrought tungsten attached to the face. This is similar to the platinum targets which have been in use for some years. The function of the copper is simply to conduct heat away from the tungsten and to act as a heat storage reservoir. In this latter capacity it is much more effective than would at first seem possible, owing to the fact that while the rate of energy input is high the time is correspondingly short, a single excitation of the tube lasting for perhaps only a half second. It is interesting to note that it would take an energy input of over 60 kilowatts acting for a second to raise the temperature of a half pound mass of copper by 700 deg. cent.

The second type is for the first time made possible by the advent of wrought tungsten. In this type, the target consists entirely of refractory metal, and this is allowed to heat up to such temperatures that it is capable of radiating relatively large quantities of energy. Tungsten at its melting point, is capable of radiating about 375 watts per sq. cm. This means that a tungsten disc 3 cm. in diameter and 0.2 cm. thick would, if its entire mass were at the melting point, be radiating energy at the rate of over 5 kilowatts. (The same cylinder, if made of platinum and run at 1750 deg., the melting point of platinum, would radiate only about one twentieth as much). It would not of course be practicable to run the entire tungsten mass at the melting point, and, owing to the resistance to heat flow, the focal spot would of course come to the melting point while the periphery was at a considerably lower temperature. But such a target would at least be able to radiate continuously relatively large amounts of energy.

The target has, for a long time, been the most vulnerable point in the tube, but this is no longer true. For either of the above types of tungsten target can be made so good that failure of the tubes as they are now built will be due to other causes.

THE TUNGSTEN OR MOLYBDENUM-WOUND ELECTRIC FURNACE

This has been fully described in an article by Winne and Dantsizen[4]. This is not only a useful adjunct to scientific investigation work; but has already become a very important factory tool. When wound upon a body of alundum, either of these metals makes possible the attainment of higher temperatures than can be obtained with a platinum-wound furnace. And as higher and higher melting refractories are produced the temperature range of this furnace will be extended.

TUNGSTEN PROJECTILES

The use of wrought tungsten as a projectile is being carefully investigated. It offers, in this field, possibilities not possessed by any other metal.

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[4] R. Winne & C. Dantsizen, *Transactions Am. Electrochem. Soc.* Vol. 20 pp. 287 to 290 (1911).

The present small arm service projectile is made of lead with a jacket of copper-nickel alloy. The principal advantage of lead over iron, which would of course be cheaper, is that it has a higher specific gravity. Because of this fact a lead bullet will have a smaller cross-section, and will therefore encounter less air resistance to its flight, than will an iron bullet of the same weight, and will therefore give a flatter trajectory and longer range. An iron bullet of the same diameter as the lead bullet could of course be given the same weight by increasing its length. But this would at once necessitate giving it a higher rotational velocity to keep its axis tangential to its flight. To impart this added rotational velocity calls for the expenditure of energy and so leaves less for velocity of translation. The lead bullet then with its higher density makes possible a flatter trajectory and longer range. With the exception of tungsten, lead is the densest metal which can be considered for this purpose, for gold is the cheapest of the other elements having a higher specific gravity than lead. The density of wrought tungsten is 19.3 while that of lead is 11.5.

For military purposes, the softness of lead is not an advantage, a soft nosed bullet being tabooed in civilized warfare. For this reason and because of the fact that it is too weak to hold the rifling, it has to be jacketed with the copper-nickel alloy. To take the rifling and to act as a gas check, the tungsten bullet will require a copper band or its equivalent at the base.

The hardness and high tensile strength of wrought tungsten will give high penetrating power.

The high melting point of tungsten will prevent it from being harmfully upset at the base by the combined action of the high temperature and rapid impact due to the combustion of the powder charge. (An unsymmetrical upsetting of the base of a projectile is very prejudical to accuracy).

It would be a very simple matter to calculate the constants of the trajectory of a tungsten projectile were it not for the fact that the high density removes it too far from the present base line. For such calculations one quantity is lacking, the so-called "form factor." This factor could itself be calculated if it contained, as the name would seem to imply, only the dimensions and the specific gravity, but there are also involved in it all of the errors due to simplifying assumptions which have been made in connection with the mathematical derivation of formulæ. It therefore becomes necessary to experimentally determine the constants of the trajectory of tungsten bullets, and this work is now being carried out.

Chemical Ware of Tungsten

Because of its inertness to many chemical agents, wrought tungsten in the form of dishes is certain to find many industrial applications. Small dishes have already been made successfully, and work is already under way looking to the production of larger sizes.

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THIRTY YEARS' PROGRESS IN THE ELECTRIC FURNACE

BY F. A. J. FITZGERALD

There has been so much written about the electric furnace since it entered into regular commercial use about 20 years ago that the presentation of a paper on the subject treating it in a general way is not apt to be interesting. But a promise to attempt the preparation of such a paper having been given, it was thought that there might be some interest attaching to a review of the development of some furnaces during the past 30 years. Moreover, it is often useful to look back over ground that has been covered in order to obtain suggestions as to the best direction to be taken in attempting further advances.

It is now 30 years since Sir William Siemens melted about 20 pounds of steel, as well as platinum in notable quantities in an electric furnace with which he had been experimenting since 1878, and since then the electric furnace has so far developed that there are great numbers, both in Europe and this country regularly engaged in the commercial manufacture of steel. While it is true that others had made some use of electrothermic methods at a much earlier day, for example Despretz, whose source of current was 600 Bunsen cells, yet Siemens' furnace must be considered the first really practical one, coming as it did after the invention of a cheap source of energy—the electric generator.

Siemens' work is of particular interest because he saw the possibility of using the electric furnace for steel manufacture, and, so far as the principles are concerned, they are the same as those in actual commercial use to-day. One of his furnaces was made of a graphite or other refractory crucible enclosed in a jacket of heat insulating material. Inserted in the bottom of the crucible was an electrode of iron, platinum or carbon, while passing through the cover of the crucible was another electrode. The latter was connected to an automatic regulating device consisting of a solenoid, this serving to vary the length of the arc and thus keep the rate of generation of energy constant. In working the furnace the steel or other metal was introduced into the crucible and made contact with the lower electrode, while an arc was drawn between the upper electrode and the charge. In such a furnace Siemens melted steel in quantities of more than 20 pounds.

In another form of electric furnace devised by Siemens, the electrodes entered the crucible in a horizontal direction near the top and opposite one another so that an arc was formed between them and heated the charge below by radiation.

Siemens' work must be considered as the forerunner of at least two well-known kinds of electric steel furnaces which are in existence to-day in actual conmercial use for the manufacture of steel, although he never was able to do commercial work with his apparatus because electrical engineering was not sufficiently advanced.

The growth of the Siemens' electric furnace for steel making was at first slow for numerous practical difficulties in its working had to be overcome, but so many of these have at last been met successfully by men like Heroult, Girod, Stassano and others who have modified the apparatus in various ways, that now we have furnaces like those of the Steel Corporation in Chicago and Worcester working on charges of 15 tons of steel.

Siemens in his furnace used direct current and laid particular stress on the point that the charge should be connected to the positive side of the circuit, since it is well known that in the electric arc it is at the positive electrode the main generation of heat occurs. In the modern furnaces, however, alternating currents are used for obvious reasons, and the surface of the molten bath is covered with a layer of slag which becomes intensely heated, not only by the arc but by the current which it carries. In this way ideal conditions are obtained for refining the metal as the steel and the molten slag between which chemical reaction is desired are intensely heated at their surfaces of contact. Moreover, the slag effectually prevents the introduction of carbon from the electrodes into the metal. The problem of regulating the electrodes automatically has also been successfully worked out by means of the well-known Thury regulator, though it would seem that this could be simplified.

There were, of course, a large number of metallurgical problems to be worked out in connection with the steel furnace, but these have apparently been met successfully, and we finally have the electric furnace working alone commercially, or what is perhaps more generally important, acting as an auxiliary to fuel heated furnaces. The most serious problems connected with furnaces of this type at the present time are those relating to electrodes and roofs. Some years ago when the electric furnace was working on a much smaller scale than is demanded to-day, the strongest argument advanced against it was that the cost of heating by means of an electric current must of necessity be so excessive that the idea was impracticable. That, however, is criticism seldom heard today for it has been found that in actual practice the furnace can be so used that the question of cost of electrical energy is by no means of the first importance. On the other hand, little used to be said about electrode cost, but now that is a most vital question and is apt to enter into the total cost of working as a much larger item than power.

The manufacture of large carbon electrodes, say 20 in. (50.8 cm.) square and from 7 to 10 ft. (2.3 to 3.04 m.) long, is by no means easy, and even when they are successfully made in the electrode factory they may go to pieces in the furnace. Even if they do not break there is the problem of "butts." Suppose a large electric steel furnace with the roof three ft. (0.91 m.) away from the bath, then it is safe to say that when the electrode holder is lowered down and comes in contact with the roof of the furnace, that there will be a carbon "butt" about four ft. long (1.22 m.) which must go in the scrap pile. Apparently this serious difficulty is going to be overcome by electrodes which can be fastened end to end so that they may be continuously fed into the furnace, and thus there will be no waste from "butts". Within the last few months there has been a good deal of work done in this direction and the results are very promising. The electrodes are made with a circular cross-section instead of square and have threaded sockets in the ends so that by means of threaded plugs the electrodes may be fastened together and thus fed continuously into the furnace without any waste.

This, as has been said, is promising, but has the limit of the electric steel furnace been reached as regards size? Except as regards electrodes there is no reason to believe that it has, but the 15 ton furnaces working now, need electrodes about 20 in. (50.8 cm.) in diameter, and if the size is doubled and the general design is kept the same, electrodes 27 or 28 in. (68.5 or 71.1 cm.) in diameter will be required. Perhaps these can be made and can be used continuously as described above, but the writer believes that development in this direction is a mistake, and that far better results can be obtained by multiplying the number of electrodes and keeping the size within reasonable limits. This is not merely a question of avoiding the difficulties of large electrode manufacture, but involves more efficient and satisfactory working of the furnace. It will readily be seen that distribution of temperature in the furnace is bound to be better as we multiply the relatively small areas where the heat is generated, and this is an important consideration. The objection that is raised to this proposal is the difficulty of regulating the rate of generation of energy at the various electrodes. It does not seem that this difficulty is a real one.

The roof problem is altogether a different one. It must be remembered that the heating effect in the steel furnace is generated in an arc and in a resistor formed by the slag, and that consequently the surface of the slag is intensely hot, particularly where the arc strikes it. These conditions are very severe and combined with the corrosive action of the lime which is vaporized from the slag, make the roof renewals a heavy item in the cost of electric steel.

This problem has recently been the subject of careful study in two research laboratories, with one of which the writer is connected. As a result of a great deal of experimental work a brick made of silicon carbide has been manufactured which it is believed will have a much longer life in the steel furnace than the silica brick now used. The brick is made by taking powdered or granular silicon carbide, mixing it with a suitable temporary binder, such as a solution of dextrine, molding and then heating in an electric furnace to the temperature at which silicon carbide is formed. Bricks made in this way have been used in the roof of an experimental steel furnace in one of these laboratories and then put to the severest test possible. The bottom of the furnace was purposely raised well above the normal level so as to bring the surface of the slag as close to the roof as possible, the actual distance in some experiments being only 10 in. (25.4 cm.) Then the furnace was worked at double the normal rate of generation of energy so that the heating of the roof was very intense, so much so that an ordinary silica roof would melt down rapidly and be completely destroyed in a single heat. Even under these very severe conditions the silicon carbide roof stood up perfectly. Experiments have also been made in other steel furnaces and these results confirmed. The most serious objection to a roof of this kind is its relatively great cost, but if it lasts a sufficiently long time it is nevertheless economical.

Twenty-five years ago Ferranti in England and Colby in this country worked on the very interesting furnaces known as the induction type. In this the secondary of a transformer consists of the metal to be melted. As in the case of the Siemens furnace the original inventors were too far ahead of the times and it was not till 10 or more years later that any commercial application of the furnaces was made. Since then the induction furnace has developed considerably and is now used with success in the manufacture of steel. An objection to the induction type is that its first cost is very great and certain problems connected with it become very serious when it is desired to build furnaces of large capacity. The worst of these is the very low power factor of the furnace. To overcome this objection it is necessary with large furnaces to have a generator furnishing currents of excessively low frequency. Thus, at the Völklingen steel works a generator giving a current of 15 cycles is used, and for larger furnaces it has been proposed to use a five-cycle current. In an experimental induction furnace plant built by the writer's laboratories for an electric furnace company at Niagara Falls, the low power factor was corrected by using a synchronous motor as a condenser.

Nearly thirty years ago the Cowles brothers were working with the electric furnace in attempts to heat the charge of zinc retorts by electrical means. The principle involved in this case was mixing with the ore to be reduced a certain amount of carbon which not only acted as a reducing agent, but made the charge as a whole a conductor of the current. This furnace may be considered the forerunner of an immense number of electric furnaces in operation today, furnaces for making calcium carbide, the ferro alloys, iron ore smelting, graphitizing, etc. The Cowles furnace was a small one, but since its day the development of the electric furnace helped by the corresponding development of electrical apparatus has led to the construction of units of continually increasing size. To follow up the development of these furnaces would certainly trangress the limits of this paper, and instead, the development of a somewhat different type will be considered because the writer has been more intimately associated with it, and because it contains points which are, perhaps, of more particular interest to the electrical engineer.

In Acheson's first experiments which led him to the discovery of silicon carbide (carborundum) he used a furnace of the Cowles type. It consisted of a small brick box with carbon terminals at each end so arranged that they could be moved in and out in a horizontal direction. This box was then filled with the mixture of sand and coke (clay and coke in the earlier experiments) and the terminals brought together, or very close to each other, and then gradually withdrawn as the furnace heated. It was soon observed that a more satisfactory way of constructing the furnace was to have stationary terminals connected to each other by means of a resistor composed of granular carbon and then surround this with the charge. With such an arrangement it was necessary to have some means by which the voltage could be regulated so as to keep the rate of generation of energy in the resistor constant throughout the run. This was found by Acheson to be a much more satisfactory way of working the silicon carbide furnace, and by experiment he found the best dimensions for his resistor. In the original small plant where the furnaces had a capacity of about 100 kilowatts the generator supplied current to a great bank of small transformers so that variations in the voltage could be obtained by suitable connections of the secondaries. When, however, a plant was established at Niagara Falls using furnaces of 750 kilowatts the problem of varying the voltage at the furnace terminals became important. This was solved by the construction of a large induction regulator to be used in the secondary circuit of the transformer which stepped down the primary current of 2200 volts to 160 volts. The induction regulator then made it possible to vary the e.m.f. by 60 volts on either side of this, so that at the furnace terminals the total range was from 100 to 220 volts. For furnaces of this resistance type the induction regulator is an ideal apparatus, and it is to be regretted that it is not more generally used. The objection raised to it is usually its relatively high cost, but the convenience and simplicity of the apparatus far more than compensate for the extra cost. In working with a furnace having a carbon resistor the resistance when starting is high and, consequently, to save time it is necessary to start the furnace with a high voltage. When the resistor becomes hot its resistance progressively decreases and the voltage must then be decreased to keep the rate of generation of energy constant. If this is done in a series of steps the results are not satisfactory, for when the maximum kilowatts are reached and the voltage is lowered one step the kilowatts are decreased proportionally, and in large furnaces it is a long time before the resistance drops to the point where the desired rate of generation of energy is again reached. This is a most inefficient method of working and the consequent loss will more than pay the interest on the cost of suitable apparatus for regulating the voltage.

Even at the time when these much larger furnaces were built the theoretical conditions involved in their construction were not understood, nor indeed for long afterwards. Thus, when the Niagara furnaces were first built the dimensions of the resistors were found to be altogether wrong, and about that time when the writer took charge of the furnace department experiments were tried with flat resistors, though an appreciation of the theoretical conditions of the problem shows at once that, other things equal, the resistor of circular cross-section must be best.

In any furnace in which the charge surrounds a resistor heated by means of an electric current it is obvious that the important consideration is the rate of generation of energy per unit surface of the resistor. The surrounding charge, or whatever it is desired to treat, can at a definite temperature absorb heat at a definite rate. Therefore, if it is desired to preserve the charge at a definite temperature it is necessary to generate the heat only so fast as the charge will absorb it. In other words, it is necessary that the watts should be a certain definite amount per unit surface of the resistor. The knowledge of the absolute value of the temperatures in such furnaces as those used in making silicon carbide is very scant, although some excellent work is now being done on this subject; but from the data obtained experimentally and the theoretical considerations of the working of such furnaces, it is possible to calculate relative temperatures with considerable accuracy.

This was well illustrated in the experimental work done by the writer in the difficult problem of making what Acheson called "siloxicon." This substance is formed by the reduction or partial reduction of silica and is combined in some way with carbon.

The great difficulty in making the material is due to the fact that at a temperature very slightly above that at which the reduction of silica by carbon begins the process goes too far and the well known crystalline silicon carbide is formed. In order to calculate the dimensions of a resistor suitable for making the material the only data available were those which could be obtained from a study of conditions in the silicon carbide furnace. Without going into details it is sufficient to say that working in this way a furnace was soon designed which made large quantities of " siloxicon " without the formation of any serious quantity of crystalline silicon carbide.

The object in devoting so much consideration to this subject is because it illustrates in a marked manner the comparative ease with which electric furnaces can be adjusted to delicate temperature conditions. This is, of course, well known as regards small laboratory furnaces, but what we are considering now is a furnace about 30 ft. (9 m.) long, 12 ft. (3.6 m.) wide and 6 ft. (1.8 m.) high, having a capacity for a charge of about 60 tons.

The greatest progress in the electric furnace since Siemens' time has been in the arc furnaces of the kinds he used; in the induction furnaces of Ferranti and Colby; and in the resistance furnace of the Cowles type; but so far as the furnace depending on the use of a heating resistor, other than the charge, is concerned there has not been any great advance as regards apparatus of large capacity. The explanation of this is found in the structural difficulties involved. It is believed, however, that those can be overcome, and, moreover, that it is well worth while spending considerable effort in this direction. In the laboratories with which the writer is connected much time has been devoted to a study of this type of furnace, and more or less successful furnaces worked out. This kind of furnace for example lends itself very readily to a form of apparatus which is bound to be developed sooner or later where the heating is accomplished by means of fuel as well as the electric current. This has been done with success in furnaces on a large scale where the preliminary heating is carried on by means of fuel until a temperature is reached where it becomes economical to use the electric current to get the higher temperatures desired. Moreover, in such furnaces we may usefully employ nearly all of the electric current by jacketing with burning gases which eliminates nearly all radiation from the interior of the furnace by supplying the inevitable heat losses from fuel rather than electricity.

The question of the loss of heat through the walls of electric furnaces is a matter that is now attracting a great deal of attention for its importance is very great. The writer has recently had occasion to give this matter careful consideration owing to the inefficient working of an electric furnace designed for some special smelting work. The testing of this furnace showed that the heat losses amounted to 50 per cent but merely covering 25 per cent of the outer surface of the furnace with a moderately good heat insulator reduced this loss nearly 20 per cent.

Before closing the remarks on this type of furnace it may be of interest to note some experiments recently carried out with an electric kiln at the writer's laboratories. The kiln is the invention of Mr. John L. Harper and is of the continuous channel type. Two long channels run parallel to each other and through each of these passes a train of trucks in opposite directions. The center part of the kiln is heated electrically. With this arrangement, the trucks with their contents passing from the high temperature part of the kiln, give up their heat to the trucks going to the high temperature part. Theoretically with an arrangement of this sort all that is required of the electric energy is to supply the heat losses from the kiln. Various experimental furnaces of this kind have been built, the chief object in view being a study of the structural features of the kiln, such as the best form of resistor, refractory linings, etc., also tests of the control of temperature, maximum temperature available, control of atmosphere, heat insulation, etc. The kiln was used for various purposes, but the principal experiments were made on procelain with the production of " biscuit " and glazed ware. The control of temperature was found to be very good and the kiln was extremely simple to work, requiring very little attention.

It is not pretended that in this paper the subject of the development of the electric furnace has been more than superficially treated, the attempt being simply to take a few examples which would illustrate how the electric furnace has developed and indicate some of the problems involved in its construction and working today. This, naturally, confined the subject to a certain extent to matters within the writer's own experience; but it is hoped that this may prove somewhat more interesting than a mere catalogue of modern furnaces compiled from the literature on the subject.

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SIMPLIFICATION OF ELECTRO-THERMAL CALCULATIONS; THE WATT AND THERMAL OHM

BY CARL HERING

Modern tendencies are toward greater efficiency, in machinery as also in a more scientific management and in many other directions involving the saving of useless labor or wasted efforts, as exemplified for instance in simplified spelling the use of abbreviations, the Esperanto language, etc. Obsolete, old-fashioned and inefficient machinery is willingly discarded for that which is more efficient; obsolete methods of management are discarded for better ones; economy in the physical labor of man is carefully studied and practiced; yet in the very process which every engineer himself uses and which is more personal to him than any other, namely, the process of doing his mental work, the average engineer completely ignores the adoption of more efficient methods even when they are within his reach. In our numerous daily calculations we still adhere with astonishing tenacity to our antiquated, cumbersome, irrational, time robbing, inherited systems of measures, although we have within reach systems which are far more efficient in the economy of mental energy.

We have before us an excellent example in the so-called absolute or c.g.s. system of units, which is so invaluable to the physicist. In this there is always one, and *only one*, well defined unit for every physical quantity, and practically all the conversion factors fall out of the calculations, as they are unity, because all the units are connected with each other by a unity relation.

We could readily have the benefits of such an ideally simple and time saving system in our daily calculations by merely using as our practical units some fixed decimal multiples of these generally inconveniently small or large c.g.s. units. Our wise forefathers gave us some of these benefits when they established our present simple and very satisfactory system of practical electric units in which all relations are unity, and we should be everlastingly thankful to them for their forethought and wisdom.

But realizing the great mental inertia which has barred us in this country from the benefits of a great step in this direction in the form of the metric system, the introduction at the present time of such a more complete and radical change for the better as mentioned above, would seem hopeless. The chief reason is that each individual considers only his own small special field of work; there are too few broad-minded men who can see the matter in the light of the benefit to the community as a whole, and who can forget their own temporary inconvenience.

Although there exists this strong opposition to improving the efficiency of our mental work by changing existing units into more rational ones, there is an opportunity to at least take a step in this direction whenever an occasion arises to create a new unit where none has existed before. In fact in such a case it is, in the writer's opinion, a moral duty to our descendants to make such new units decimal multiples of the c.g.s. units, as those who established our electrical units did.

Such an occasion has arisen lately in connection with the flow of heat through bodies, a branch of applied science to which more attention has been given recently and will undoubtedly be given to a much greater extent in the near future; it has its application in the economy of thermal processes. Heat cannot be confined like electricity by practically perfect insulators; it will flow more or less through all bodies, hence will escape and be lost, thereby decreasing the efficiency of a thermal process. It therefore becomes important to be able to measure, calculate and predetermine such flows, and to do this requires that units be established for quantitatively expressing the physical quantities involved. The very rapid introduction of electric heating is making this important, particularly as its commercial success is dependent so largely, if not almost entirely, on the greater ability to prevent a waste of the energy, the prime cost of which is generally greater than that of combustion heat.

There is some property of heat which causes it to flow, another which offers resistance to such a flow, and as this resistance is different in different materials there is a thermal resistivity of materials; there is therefore also a conductance and conductivity;

the quantity of heat must be measurable, as also the current or flow of heat. To express, measure and calculate these quantities intelligently and conveniently, there should be a unit for each.

The purpose of the present article is to point out what the most rational values of these different units are and to urge their general adoption.

The selection of new units should, in the writer's opinion, be governed by two principles; one is to bring the new unit into the group based on the c.g.s. units by making it some decimal multiple of the corresponding unit in that system; and the other is to choose these decimal multiples so that in the most frequently occurring calculations the relations between the different units are unity, just as in our existing system of electrical units, and in the c.g.s. system.

The cause of a flow of heat is a difference of temperature. As there is unfortunately no unit of temperature in the c.g.s. system, we are compelled to adopt one of the thermometer scales and there is presumably no question that among these the centigrade system should be preferred. Hence the unit of difference of temperature which should be used in the present new group of units is the centigrade degree.

For expressing the flow of heat it would at first seem natural to use as a unit a transmission of one of the customary units of heat per second, like calories per second. It would then however not be in that preferred group of rationally interconnected units to which the c.g.s. and the electrical units belong, as there is no heat unit in that system. Heat is only one of the various forms of energy and one of the basic principles of a rational, interconnected system of units, is to have only one unit for each physical quantity no matter what form it is in. The c.g.s. unit of energy is the erg, hence this includes heat as well as all other forms of energy. It is therefore not correct to call a calorie per second a c.g.s. unit, as is not uncommonly done by able writers.

A flow or current of heat is physically a rate of transmission of energy, hence the only rational unit for measuring it in the c.g.s. system is the erg per second. The physicist would use this unit in his analytical deductions. This is more rational also because in many of our processes energy is transformed, sometimes repeatedly, from one form to another, and as it is the same energy it is not rational or mentally economical to keep changing the units in our calculations each time this same energy merely changes its form; the physicist would certainly not do so in an analytical discussion, and as his method is far simpler why should not the engineer also avail himself of this privilege; it is directly within his reach.

According to the above principles therefore the practical unit of a flow or transmission of energy, be it in the form of heat or in any other form, should be a decimal multiple of the erg per second. As such a practical unit of a very suitable order of magnitude already exists in practice in the watt, it would be irrational to create a new one. Hence in the simplified system here suggested, the watt is chosen as the rational unit for the flow of heat. It is equal to 10,000,000 ergs per second.

When it is said that a heat flow of say 10 watts is passing through a thermal conductor, or is flowing out of its end or from a surface, it means that the amount of heat flowing is equal to that which would be generated continuously in an electrical conductor, lamp or coil in which 10 watts of electrical energy is being converted into heat. No conversion factors are then required although the energy has changed from the electrical to the thermal form.

Some persons argue that in this as also in the adoption of the kilowatt in place of the horse power, we electrical engineers want others to adopt our electrical units to the exclusion of the older units, and they ask why we should not change ours to suit the older ones. This is manifestly unjust; what we ask is not that the other units be "electrified," but merely that these scattered, arbitrary, incommensurate and often quite irrational units should be changed so as to bring them into that rational c.g.s. group in which (nearly) all conversion factors disappear, and to which the electrical units already belong; and whenever the magnitude of the practical electrical unit for that quantity is of a convenient order, it certainly simplifies matters to adopt this already existing unit, like the watt in this case, instead of creating another one.

Having selected the centigrade degree as the unit of the cause of thermal flows, or what might popularly be called the thermal pressure, and having chosen the watt as the unit of the flow, then the rational unit of the resistance which opposes such a flow, is that resistance which will allow one watt of heat current to flow through it when the difference in temperature at the ends is one centigrade degree. This means that these three units bear a unity relation to one another, just, as in accordance with Ohm's law, the unit ohm was so chosen that one volt will cause one ampere to flow through it.

This unit, which was suggested by the writer over a year ago therefore is analogous to the ohm and the calculations involving it are like those for electrical resistances. The thermal resistance of a centimeter or inch cube is the specific resistance or resistivity, and the total resistance is equal to this resistivity multiplied by the ratio of the length to the section.

The flow of heat through a body in watts (assuming it to be perfectly insulated on the lateral surfaces) will be numerically equal to the difference of temperature at its ends, in centigrade degrees, divided by the thermal resistance of the body, provided the unit of resistance just defined is used. That is, if W represents the flow in watts, T the drop of temperature in centigrade degrees and R the thermal resistance in terms of this unit, then $W = T/R$, which on account of its identity with Ohm's law might be termed the thermal Ohm's law, especially as it is believed that Dr. Ohm discovered his famous electrical law through the analogy of the flow of electricity with the flow of heat, the laws of the latter having been determined earlier.

Owing to the analogy between the unit of thermal resistance as thus defined, with the electric ohm, and in deference to Dr. Ohm who about a century ago first pointed out the analogies between the two laws, the writer suggested calling this unit of thermal resistance the *thermal ohm.*

When a unit is often used, it facilitates and simplifies matters to give it some distinctive name. It is for instance very convenient to be able to use the simple name " ampere " for the unit of an electric current, instead of its more cumbersome though quite correct equivalent the " volt per ohm." Or to use the name " ohm " in place of " volts per ampere." It seems almost essential to name two of such an interconnected group of three units, then why not name the third one also. Such a distinctive name is also useful to distinguish a unit more readily from other units of the same physical quantity when several are in use, as for instance in the case of feet, meters and inches, or pounds and kilograms, or horsepowers and kilowatts, etc.

Some persons however do not agree with the present writer in the advisability of thus naming this new unit, although they agree that the magnitude of the unit is the best; they prefer to define it each time it is used by stating that a thermal resistance when given in terms of this unit is equal to so-and-so many " degrees per watt," on the same principle that the name of the ohm is unnecessary as this unit could correctly be specified as the number of " volts per ampere." Unfortunately neither of these two phrases carries with it the often very useful conception that the physical quantity referred to is a resistance. The writer thinks it better to give it a characteristic name and therefore advocates the term " thermal ohm " as a simple one which carries with it an explanation that it represents a thermal resistance, while the last word " ohm " indicates that it belongs to the same ideal group of units to which the electric ohm belongs, in which the values are always some decimal multiples of the c.g.s. units.

Whenever the difference of temperature between the ends of a thermal conductor, stated in centigrade degrees, is divided by the thermal flow in watts, the quotient, being the degrees per watt, is the thermal resistance in thermal ohms.

The writer acknowledges that Dr. A. E. Kennelly first suggested this appropriate name for a unit of thermal resistance but had applied it to one of a different magnitude, namely the one based on the gram calorie, therefore bringing it into a group which is foreign to and incommensurate with the true c.g.s. group; but as that name for that unit had apparently not come into general use, although it had been suggested a number of years before, the writer took the liberty to retain what he considered a very appropriate name but to change the numerical magnitude of the unit so as to bring it into the more rational group.

That this unit is of a convenient size for use in practical work is shown in various tables of values of the thermal resistivities of various materials* and surfaces† which were gathered from various sources and reduced by the writer to thermal ohms. The metals for instance have thermal resistivities of about one-quarter to three thermal ohms for one centimeter cube; solid refractory materials like brick, about 40 to 200; loose granular or fibrous materials about 300 to 4000. Surfaces from which heat is emitted seem to have a surface resistance of several thousand to less than one thermal ohm per square inch, depending upon the nature of the surface and the temperatures.

In thermal problems like in electrical ones, it is often convenient and time saving, in the calculations occurring in practice, to use the thermal resistances of bodies as resistances and not carry the calculation each time to the extent of determining the loss of heat through it, as was formerly done before thermal resistances came into more general use. This would apply for instance where such resistances are used as thermal insulators. This often saves many unnecessary calculations, and it also eliminates the temperature from such calculations, except in so far as the temperature coefficient of the thermal resistivity is concerned. A wall of a furnace or the thermal insulation of a cooking device can be specified simply as having a resistance of so-and-so-many thermal ohms.

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* *Flow of Heat through Bodies.* Metallurg. & Chem. Engineering, Dec. 1911, p. 652.

† *Flow of Heat Through Contact Surfaces.* Metallurg. & Chem. Engineering, Jan. 1912, p. 40.

Although in most engineering problems of an electro-thermic nature, like electric heating devices including furnaces, it is far simpler to use resistances instead of conductances, as is also generally true in purely electric problems, yet it may sometimes be desirable to use thermal conductances and conductivities and for this purpose the units for the latter should of course be the true reciprocals of the resistance and resistivity units. For consistency the name " thermal mho " is recommended for the corresponding unit of thermal conductance.

A more detailed discussion of this unit of thermal resistance was published by the writer over a year ago* in which article a complete set of the conversion factors were given for reducing values in other units to those in the units here suggested and the reverse, as also numerical examples illustrating the use of this unit in practice. These conversion factors are as follows:

TABLE OF CONVERSION FACTORS

(NOTE.—A flow or radiation of heat may be measured in watts, in gram calories per second, or in ergs per second. In this table the term " c.g.s. unit," that is, the absolute unit, refers to the true ones based on the erg per second; those often called " c.g.s. units " and based on the gram calorie are here given under the latter term. The centigrade degree is understood to be meant in all these units.)

Thermal Resistance.

Thermal ohms:
=centigrade degrees ÷ watts = degrees per watt.
= 1 ÷ thermal mhos.

1 thermal ohm:
= a resistance requiring 1° C. per watt of flow.
= 4.18617 gram calorie units; approx. 50/12.
= 0.0000001 c.g.s. unit of thermal resistance.

**Thermal Resistance and Conductance; the Thermal Ohm and Thermal Mho.* Metallurg. & Chem. Engineering, Jan. 1911, p. 13.

1 gram calorie unit:
= a resistance requiring 1° C. per flow of a gram calorie per second.
= 0.238882 thermal ohms; approx. 24/100.
= 2.38882 × 10^{-8} c.g.s. units of thermal resistance.

1 c.g.s. unit of thermal resistance:
= a resistance requiring 1° C. per flow of an erg per second.
= 10,000,000. thermal ohms.
= 41,861,700. gram calorie units.

Thermal Conductance.

Thermal mhos:
= watts ÷ centigrade degrees = watts per degree.
= 1 ÷ thermal ohms.

1 thermal mho:
= a conductance permitting a flow of 1 watt per degree.
= 0.238882 gram calorie unit; approx. 24/100.
= 10,000,000. c.g.s. units of thermal conductance.

1 gram calorie unit:
= a conductance permitting a flow of 1 gram calorie per second per degree.
= 4.18617 thermal mhos; approx. 50/12.
= 41,861,700. c.g.s. units of thermal conductance.

1 c.g.s. unit of thermal conductance:
= a conductance permitting a flow of 1 erg per second per degree.
= 0.0000001 thermal mho.
= 2.38882 × 10^{-8} gram calorie units.

Thermal Resistivities.

NOTE.—These are the reciprocals of the corresponding conductivity units.

1 gram calorie, centimeter cube unit:
= 0.393700 gram calorie, inch cube, unit; appprox. 4/10.
= 0.238882 thermal ohm, centimeter cube unit; approx 24/100.
= 0.0940478 thermal ohm, inch cube, unit; approx. 2/21.
= 2.38882 × 10^{-8}c.g.s. units resistivity.

1 gram calorie, inch cube unit:
= 2.54001 gram calorie, centimeter cube units; approx. 10/4.
= 0.606762 thermal ohm, centimeter cube unit; approx. 3/5.
= 0.238882 thermal ohm, inch cube unit; approx. 24/100.
= 6.06762 × 10^{-8} c.g.s. units of resistivity.

1 thermal ohm, centimeter cube unit:
= 4.18617 gram calorie, centimeter cube units; approx. 50/12.
= 1.64809 gram calorie, inch cube units; approx. 5/3.
= 0.393700 thermal ohm, inch cube units; approx. 4/10.
= 10^{-7} c.g.s. unit of resistivity.

1 thermal ohm, inch cube unit:
= 10.6329 gram calorie, centimeter cube units; approx. 21/2.
= 4.18617 gram calorie, inch cube units; approx. 50/12.
= 2.54001 thermal ohm, centimeter cube units approx. 10/4.
= 2.54001 × 10^{-7} c.g.s. units of resistivity.

1 c.g.s. unit of resistivity:
= 418617×10^{7} gram calorie, centimeter cube, units.
= 1.64809×10^{7} gram calorie, inch cube units.
= 10^{7} thermal ohm, centimeter cube units.
= 3.93700×10^{6} thermal ohm, inch cube units.

Thermal Conductivities.

NOTE.—These are the reciprocals of the corresponding resistivity units.

1 c.g.s. unit of conductivity:
= 2.54001×10^{-7} thermal mho, inch cube unit.
= 10^{-7} thermal mho, centimeter cube unit.
= 6.06762×10^{-8} gram calorie, inch cube unit.
= 2.38882×10^{-8} gram calorie, centimeter cube unit.

1 thermal mho, inch cube unit:
= 3.93700×10^{6} c.g.s. units of conductivity.
= 0.393700 thermal mho, centimeter cube unit; approx. 4/10.
= 0.238882 gram calorie, inch cube unit; approx. 24/100.
= 0.0940478 gram calorie, centimeter cube unit; approx. 2/21.

1 thermal mho, centimeter cube unit:
= 10^{7} c.g.s. units of conductivity.
= 2.54001 thermal mho, inch cube units; approx. 10/4.
= 0.606762 gram calorie, inch cube unit; approx. 3/5.
= 0.238882 gram calorie, centimeter cube unit; approx. 24/100.

1 gram calorie, inch cube unit:
= 1.64809×10^{7} c.g.s. units of conductivity.
= 4.18617 thermal mho, inch cube units; approx. 50/12.
= 1.64809 thermal mho, centimeter cube units; approx. 5/3.
= 0.393700 gram calorie, centimeter cube unit; approx. 4/10.

1 gram calorie, centimeter cube unit:
= 4.18617×10^{7} c.g.s. units of conductivity.
= 10.6329 thermal mho, inch cube units; approx. 21/2.
= 4.18617 thermal mho, centimeter cube units; approx. 50/12.
= 2.54001 gram calories, inch cube units; approx. 10/4.

As the calculations involving thermal resistances and flows of heat through them become so simple when these units are used, and are identical with the analagous electrical ones, it seems superfluous to give any numerical examples here as illustrations. Such examples are given in some of the papers that have been referred to. Attention however is here called to the fact that although the temperature coefficient of thermal resistivities are probably of about the same general order of magnitude as those of electric conductivities and therefore not large per degree, yet the ranges of temperature are sometimes so great, as in furnaces for instance, that these changes should be taken into consideration.*

Besides using watts and thermal ohms to simplify thermal calculations, it will greatly simplify numerous other calculations in electro-thermic work to apply the same reasoning to the heat unit itself, that is, to abandon all the several so-called heat units, namely the two calories, the British thermal unit, and the hybrid pound-centigrade unit, and use the watt-hour instead. This brings the heat unit into the c.g.s. group and relieves all subsequent calculations of the troublesome conversion factors involving the mechanical or electrical equivalents of heat; such conversion factors then become unity.

This is readily done by converting the values of the physical constants of materials given in calories or B.t.u., in the tables, once for all into watt-hours; the numerous electro-thermal engineering calculations based on them then become extremely simple, so simple in fact that many of them can be done mentally.

This would mean converting all such thermal constants as specific heats, latent heats, and heats of chemical combinations, once for all into watt-hours, thereby avoiding the incessant repetition of the reductions involving incommensurate conversion factors in all the numerous subsequent calculations. It would then be stated for instance that the energy necessary to heat, melt and raise the temperature of a pound of steel to a certain number of degrees is so-and-so-many kilowatt hours per pound. This is discussed in another paper by the writer.†

The conversion factors are as follows: One kilogram calorie equals 1.1628 or approximately 7/6 watt-hours; one thermal unit (pound-Fahrenheit unit or B.t.u.) equals 0.29303 or approximately 5/17 watt-hours; one watt-hour equals 0.85998 or approximately 6/7 kilogram-calories and to 3.4127 or approximately 17/5 thermal units.

It may at first seem somewhat inconsistent to use the watt-hour instead of the joule for the equivalent of the heat unit in this simplified system. But although the joule is theoretically the more rational unit, yet electric energy in practice is now universally expressed and measured in watt-hours or kilowatt-

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*See for instance a recent paper by the author read before the April meeting of the Amer. Electrochem. Society on *Effects of the Variations of Thermal Resistivities with the Temperature.*

†Paper read before the Amer. Electrochem. Society in April 1912 on "Uniformity and Simplicity in Electrochemical and Electrothermal Calculations."

hours and never in joules, hence by using the former the troublesome factor of 3600 (the number of seconds in an hour) is eliminated by becoming unity.

The simplifications in calculations by thus working within the same group as the c.g.s. units, is so great that it may often reduce the mental labor even in thermal problems which do not involve electrical energy; one would then reduce the original data at the start to this group of units, and the final results back again, which would enable one to make all the calculations involving the design and proportioning, (and these are often by far the more numerous) in the simple system, just as in some classes of work it is simpler to convert the original data into the metric system, then make all the tests and numerous engineering calculations in that system, and convert the final results back into the original units.

A paper to be presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

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(*Subject to final revision for the Transactions.*)

THE TRANSIENT REACTIONS OF ALTERNATORS

BY WILLIAM A. DURGIN AND R. H. WHITEHEAD

This paper is confined to demonstrating the existence of a characteristic of alternators provisionally named the ***transient impedance*** and to investigating the influence of this characteristic on

a. The maximum and minimum currents flowing through a 12,000-kw turbo-alternator with and without external reactance coils, under various short circuit conditions.

b. The maximum and minimum currents into different classes of faults from a system operating several such units in parallel.

c. The maximum cross currents obtainable when paralleling a unit to the system considered in (b), and,

d. The torque developed by the maximum currents of (a) and (b).

SUMMARY

From these investigations we conclude that the short-circuit currents of alternators are limited by reactances much more complex and much higher than the self-inductive reactances of the armatures, but which are constant for similar units and can be obtained for any size and type of generator by simple low-voltage short circuit tests. By means of this test value the maximum short circuit-current of a single unit may be readily computed from

$$I_m{}^0 = \frac{E_m{}^0}{z}\left(1+\epsilon^{-\frac{r}{x}\pi}\right)$$

and the maximum torque from

$$W_m{}^0 = \frac{3}{2}\,\frac{(E_m{}^0)^2}{z^2}\,r\left(1+\epsilon^{-\frac{r}{x}\pi}\right)^2$$

equations which show when developed, that the current per unit in any given short circuit is less as the number of units in parallel increases; that the maximum current always results when the short circuit occurs at the zero point of the corresponding pressure wave, independent of the particular short circuit conditions; that the maximum instantaneous torque merely varies inversely as the reactance in circuit and hence that instability of the system and generator stresses (except those in end turns) at times of short circuit, are only lessened by reactance coils in proportion to the resulting increase in total reactance; that the torque stress per unit with a given number of units in parallel may be greater or less than that with a smaller number of units, depending on the resistance of the short circuit; and that the maximum torque is entirely independent of the points of the pressure waves at which a three-phase short circuit occurs. Finally we find that the total reactance of an alternator should be at least 15 per cent per phase, divided about equally between the unit and external reactance coils, in order to secure protection of the unit from the system in cases of internal short circuit, and that even this reactance will not give complete protection from torque strains in the armature and field due to poor synchronizing and short circuits or from excessive power dissipation at faults or in oil switches in cases of breakdown.

TRANSIENT IMPEDANCE

The generally accepted theory of the short-circuit current of alternators is stated as follows by Dr. Steinmetz in *Transient Electric Phenomena and Oscillations*, page 200, paragraph 113.

"When suddenly short circuiting an alternator from open circuit, in the moment before the short circuit, the field flux is that corresponding to the impressed m.m.f. of the field excitation, and the voltage in the armature is the nominal generated e.m.f., e_0 (corrected for magnetic saturation). At the moment of short circuit, a counter m.m.f., that of the armature reaction of the short circuit current, is opposed to the impressed m.m.f. of the field excitation, and the magnetic flux, therefore, begins to decrease at such a rate that the e.m.f. generated in the field coils by the decrease of field flux increases the field current and therewith the m.m.f. so that when combined with the armature reaction it gives a resultant m.m.f. producing the instantaneous value of field flux.

Immediately after short circuit, while the field flux still has full value, that is, before it has appreciably decreased, the field m.m.f. thus must have increased by a value equal to the counter m.m.f. of armature reaction. As the field is still practically unchanged the generated e.m.f. is the nominal generated voltage and the short circuit current is,

$$i_0' = \frac{e_0}{x_1} \qquad (1)$$

Reactance is used in place of impedance in this equation as in comparison the resistance of the armature is negligible. It is to be remembered that x_1 is the self-inductive reactance of the armature due to flux linked only with the armature conductors and hence as this can be calculated or at least approximated from the design of the machine, an estimate of the short-circuit current corresponding to the theory can be made. The equation gives this current as an a-c. phenomenon, that is, with equal positive and negative half waves, but since it is really a transient phenomenon and may, therefore, have the initial waves displaced entirely above or below the zero value, the true maximum possible value is twice that shown by the equation, or

$$I_m^0 = \frac{2\,E_m^0}{x_1} \qquad (2)$$

The short-circuit tests made during the early part of 1911 on a 12,000-kw., 9000-volt, 25-cycle turbo-alternator at the Fisk Street Station of the Commonwealth Edison Company as described in Messrs. Schuchardt's and Schweitzer's paper on "The Use of Reactances with Large Central Stations," and Mr. E. B. Merriam's paper on "Some Recent Tests of Oil Circuit Breakers," both in Volume XXX of the PROCEEDINGS of this Institute, gave an unusual opportunity for checking this theory, and the great discrepancy between the estimated values of short-circuit currents and those actually found lead to the results now presented.

In these tests 167 short circuits, through circuits with 0 per cent, 3.9 per cent, or 6.3 per cent external reactance were thrown on the alternator at open circuit voltages from 1000 to 9000 volts. The peak value of the initial cycle of current in the three phases for each delta short circuit as obtained from the oscillograms then taken is plotted in Fig. 1 for 6.3 per cent external reactance, in Fig. 2 for 3.9 per cent external reactance and in Fig. 3 for 0 per cent external reactance. In Fig. 4 similar values are plotted for all single-phase and three-phase four-wire short circuits. The upper solid lines drawn in these plots, thus represent the maximum currents from test, and making the single assumption that current continues proportional to voltage beyond the limits of the plot, the figures of column 5, Table 1 give the test results for the maximum peak values of short-circuit currents corresponding to the various values of external reactance.

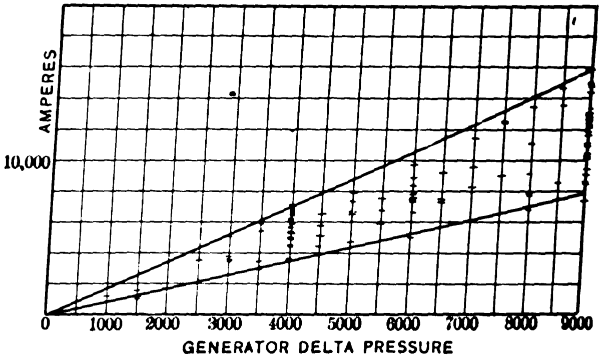

FIG 1.—INITIAL PEAK VALUES OF CURRENTS IN THREE-PHASE DELTA SHORT-CIRCUITED TESTS.
Through 6.3 per cent external reactance.

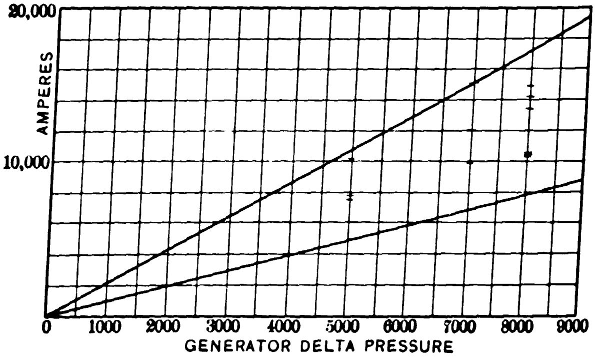

FIG. 2.—INITIAL PEAK VALUES OF CURRENTS IN THREE-PHASE DELTA SHORT-CIRCUIT TESTS.
Through 3.9 per cent external reactance.

With external reactance in series with the armature the fundamental equation becomes,

$$I_m^0 = \frac{2\,E_m^0}{x_1 + x_{ext}} \tag{3}$$

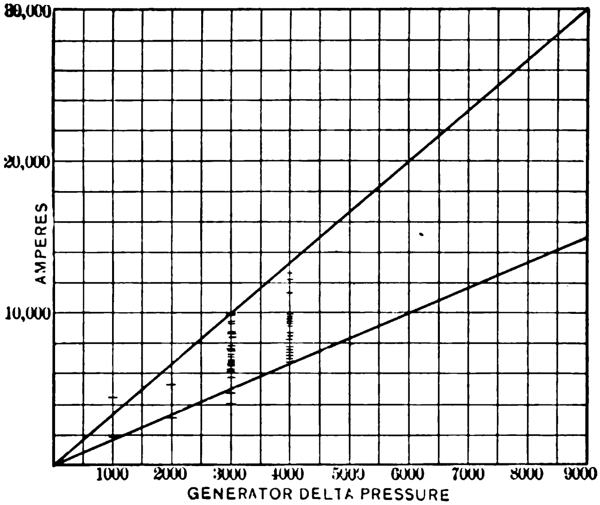

FIG. 3.—INITIAL PEAK VALUES OF CURRENTS IN THREE-PHASE DELTA SHORT CIRCUIT TESTS THROUGH ZERO EXTERNAL REACTANCE.

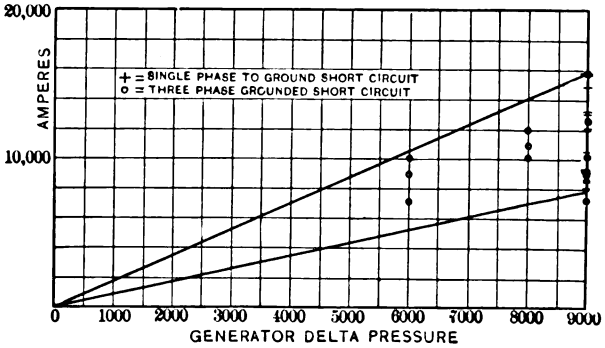

FIG. 4.—INITIAL PEAK VALUES OF CURRENTS IN BOTH SINGLE-PHASE TO GROUND AND THREE-PHASE GROUNDED SHORT-CIRCUIT TESTS.
Through 6.3 per cent external reactance.

For the particular generator tested, x_1 was estimated by various engineers as about 2 per cent or 0.135 ohms, and using this figure in equation (**3**) the values of column 4, Table 1, were computed. The actual current without external reactance is seen to be only 28 per cent of this computed value, and making all due allowance for inaccuracies in estimating x_1, it seems evident that the current is limited by some reactance beside those contemplated in the original theory. Substituting the test values of I_m^0 and E_m^0 in equation (3) and solving for the denominator of the second member, we obtain the values given in column 6, Table 1, and subtracting x_{ext} from these, the figures shown in column 7 result for the value of the total effective internal reactance. The agreement of these last figures obtained from three series of tests made under different conditions of external circuit is striking. Indeed, the variation from a mean of 0.5 ohm is well within the experimental error of oscillograph work, and although *the transient reactance*, as the writers have called this quantity probably varies somewhat with conditions of field circuit and armature current even during the middle third of the first cycle of short circuit, these variations are comparatively small and for the purposes of the paper the transient reactance is taken as constant during this period under all conditions of short circuit. Considered over the total period of the transient short circuit phenomenon, it is, of course, a variable increasing from a lower limit x_1 to an upper limit x_0 where x_0 is the synchronous reactance developed when the machine is brought up to speed from standstill under short circuit and normal excitation.

TABLE NO. 1.

External reactance		Star Maximum Peak Values				
		Computed *		Observed current	Total reactance from test	Transient reactance
Per cent	ohms	Voltage	Current			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.00	0.000	7350	109,000	30,000	0.490	0.490
3.93	0.266	7350	36,700	19,400	0.758	0.492
6.26	0.424	7350	26,300	15,800	0.931	0.507

*Throughout this paper the following values are used for the rated voltage and current per phase:

$$E = 5.200 \quad E_m = 7,350$$
$$I = 770 \quad I_m = 1,090$$

The existence of such a transient reactance or rather the existence of complex reactions which are conveniently grouped and replaced by a single fictitious quantity called the transient reactance is shown conclusively by the test results and has, indeed, been more or less clearly appreciated for some time. Miles Walker, in his paper on "Short Circuiting of Large Electric Generators," PROCEEDINGS, Institution of Electrical Engineers, Volume XLV, page 295, states that in one case which he investigated the circuits of the eddy currents in the field poles had an equivalent inductance reduced to the armature, 2.4 times as great as x_1 and engineers in general have accepted the statement that the actual short circuit currents obtained will be less than those indicated by theory on account of eddy current reactions. But the full significance of the large current induced in the field circuit does not appear to have been clearly formulated.

Dr. Steinmetz's statement of the original theory assumes a current induced in the field of such strength as to maintain the resultant flux constant against the effects of armature reaction. The induction of this current in the field, however, is so closely analogous to simple transformer action that the effects of its flow through the highly self-inductive secondary or field circuit may be considered equivalent to adding the field inductance multiplied by the square of the ratio of transformation to the primary or armature circuit, or if

x_F = reactance of field circuit, reduced to armature,
x_E = reactance of eddy current paths in contiguous metal masses, reduced to armature,
x_2 = reactance representing decrease of total resultant flux due to energy dissipation,
x_T = transient reactance,

then,

$$x_T = x_1 + x_2 + x_E + x_F \tag{4}$$

as x_E and x_F are only effective during the transient phenomenon or while alternating current is induced in the field, this equation for the permanent three-phase condition reduces to

$$x_T = x_1 + x_2' = x_0 \tag{5}$$

In the above discussion reactance only has been considered. It is, of course, evident that the field circuit and especially the eddy current circuits possess considerable resistance and that, as more definite data are obtained, investigations must be based on the *transient impedance*. But at present, unfortunately, no figures are available for the transient resistance, and the writers have been obliged to assume that as the known armature resistance of 0.03 ohms is negligible, the values of Column 7, Table 1, represent true transient reactance and in the cases discussed below to treat the total transient resistance as negligible or as replacing an unknown part of the external resistance.

(a) *The Maximum and Minimum Currents Flowing Through a 12,000-kw. Turbo-Alternator With and Without External Reactance Coils, Under Various Short Circuit Conditions.*

One of the principal advantages of considering all the armature reactions as a single transient reactance, practically constant during the middle third of the first cycle after short circuit, lies in the fact that the short circuited armature then becomes strictly analogous for this period to a circuit possessing the same resistance and reactance upon which is impressed a constant e.m.f. equal to the nominal generated voltage e_0 (corrected for magnetic saturation). The current in such a circuit is given by,

$$i = \frac{E_m}{z}\left[\cos(\theta-\theta_0-\theta_1) - \epsilon^{-\frac{r}{x}\theta}\cos(\theta_0+\theta_1)\right] \tag{6}$$

in which equation, as applied to the short circuited armature

E_m = maximum nominal generated e.m.f. (corrected for saturation).
$z = \sqrt{r^2 + x^2}$
r = transient resistance + resistance of external circuit.
$x = x_T + x_{ext}$
θ = time from instant of short circuit.
θ_0 = phase of pressure at instant circuit is closed in terms of θ from equation $e = E_m \cos(\theta - \theta_0)$ or the time angle to the nearest positive E_m x
$\theta_1 = \tan^{-1}\frac{x}{r}$

Considering first the case where r is negligible with respect to x equation (6) reduces to

$$i = \frac{E_m^0}{x}\left[\cos\left(\theta-\theta_0-\frac{\pi}{2}\right) - \cos\left(\theta_0+\frac{\pi}{2}\right)\right] \tag{7}$$

and gives maximum values for i when $\theta_0 = \pm\frac{\pi}{2}$ or when the short circuit occurs at the zero point of the e.m.f. wave, for under these conditions,

$$i = \pm \frac{E_m^0}{x}\left(\cos \theta - 1\right) \tag{8}$$

and

$$I_m^0 = \pm \frac{2\, E_m^0}{x}$$

this being the same value as obtained from the original theory with the initial wave completely above or below the time axis (Equation **2**.) If the short circuit occurs at $\theta_0 = 0$ or $\theta_0 = \pi$ on the other hand, equation (**6**) becomes

$$i = \frac{E_m^0}{x} \cos\left(\theta - \frac{\pi}{2}\right)$$

or

$$= \frac{E_m^0}{x} \cos\left(\theta - \frac{3\pi}{2}\right)$$

giving

$$I_m^{0\prime} = \pm \frac{E_m^0}{x} \tag{9}$$

that is, the minimum initial peak of the minimum phase when the short circuit takes place at the peak of the impressed e.m.f. wave for this phase.* Under these conditions the current wave is symmetrical about the time axis and the maximum is one-half that obtained when the wave is completely displaced.

The test results are in satisfactory agreement with this last relation, the lower solid line of Figs. 1, 2, 3 and 4 being plotted for values one half those of the upper line. The fact that a few points fall below the limit indicated by the theory is probably to be explained, aside from the unavoidable inaccuracies of oscillograph measurements, by variation in the resistance of the external circuit. The importance of maintaining this resistance constant did not appear until the tests were completed, and in consequence, as the contacts of the oil circuit breaker used to open the short circuit became pitted, a resistance was introduced in each phase varying from several hundredths to perhaps a few tenths of an ohm as indicated by oscillograms of the pressure drop across the several contacts. The higher figure is by no means negligible in comparison with the reactance of the circuit and, together with the unknown transient resistance, introduced considerable variations from the purely reactive impedance assumed.

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*Initial peak is used throughout this paper as meaning the highest peak occurring in the first cycle.

Fig. 5 shows the effect of various external reactances up to 20 per cent in reducing the current of one of the 12,000-kw. generators under short circuits of negligible resistance as computed from equation (**2**), the actual test values being plotted as circles. It is interesting to note that whereas an increase of external reactance from zero to 6 per cent results in a decrease in current of about 45 per cent, an increase from 6 per cent to 10 per cent external reactance gives only about 12 per cent further decrease of current.

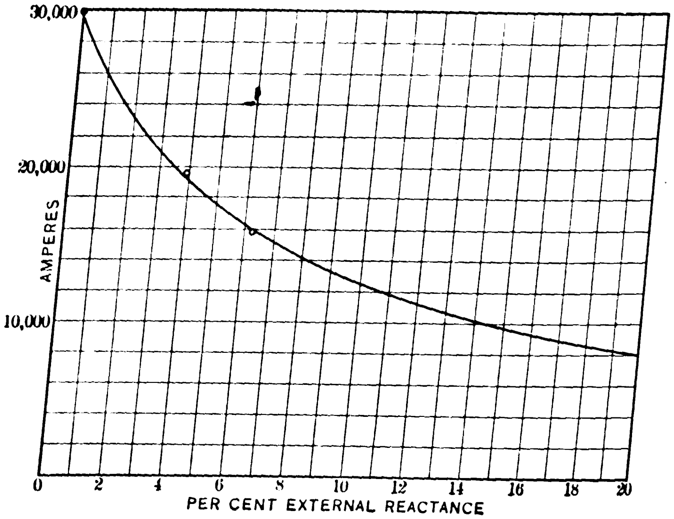

Fig. 5.—Maximum Initial Peak Values of Current through 12,000-kw. Alternator at 9,000 Volts on External Three-Phase Short Circuits of Zero Resistance and Various Reactances.

If the resistance is not negligible the analytical solution of equation (**6**) for maximum i becomes difficult and the investigation is carried out most readily by plotting various families of curves. For this purpose the variables of equation (**6**) may be grouped,

$$Y = \cos\left[\,\theta - (\theta_0 + \theta_1)\,\right] - \epsilon^{-\frac{r}{x}\theta}\cos(\theta_0 + \theta_1) \qquad \textbf{(10)}$$

and θ, $\frac{r}{x}$ and $\theta_0 + \theta_1$ considered the new variables.

Taking $\theta_0 + \theta_1 = \pi$ the family of curves given in Fig. 6 is obtained, showing the values of (**10**) for representative values of $\frac{r}{x}$ and all values of θ from 0 deg. to 180 deg. Similar families have been plotted for other values of $\theta_0 + \theta_1$ and the maxima of each of the several series made up of those curves having the same value of $\frac{r}{x}$ but different values of $\theta_0 + \theta_1$ are combined in Fig. 7 to form one of a new family of curves in which, therefore, for each value of $\theta_0 + \theta_1$ and $\frac{r}{x}$, θ has the value shown by Fig. 6 and the similar families to be necessary to make (**10**) a maximum.

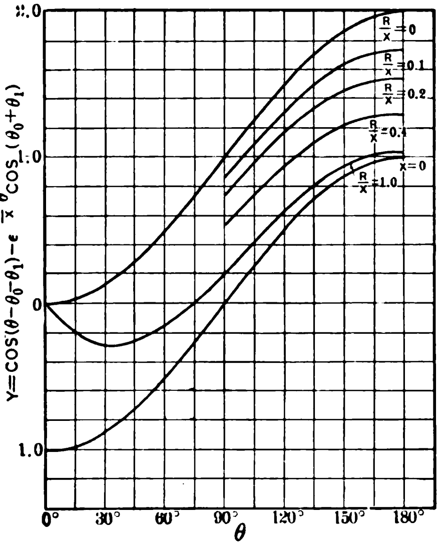

FIG. 6.—VALUES OF Y, EQUATION (**10**), FOR REPRESENTATIVE VALUES OF $\frac{r}{x}$ AND ALL VALUES OF θ FROM 0 TO π WHEN $\theta_0 + \theta_1 = \pi$.

The dotted line drawn through the peak of these last curves is found to pass through the points corresponding to $\theta_0 = \frac{\pi}{2}$

in each phase varying from several hundredths to perhaps a few tenths of an ohm as indicated by oscillograms of the pressure drop across the several contacts. The higher figure is by no means negligible in comparison with the reactance of the circuit and, together with the unknown transient resistance, introduced considerable variations from the purely reactive impedance assumed.

Fig. 5 shows the effect of various external reactances up to 20 per cent in reducing the current of one of the 12,000-kw. generators under short circuits of negligible resistance as computed from equation (**2**), the actual test values being plotted as circles. It is interesting to note that whereas an increase of external reactance from zero to 6 per cent results in a decrease in current of about 45 per cent, an increase from 6 per cent to 10 per cent external reactance gives only about 12 per cent further decrease of current.

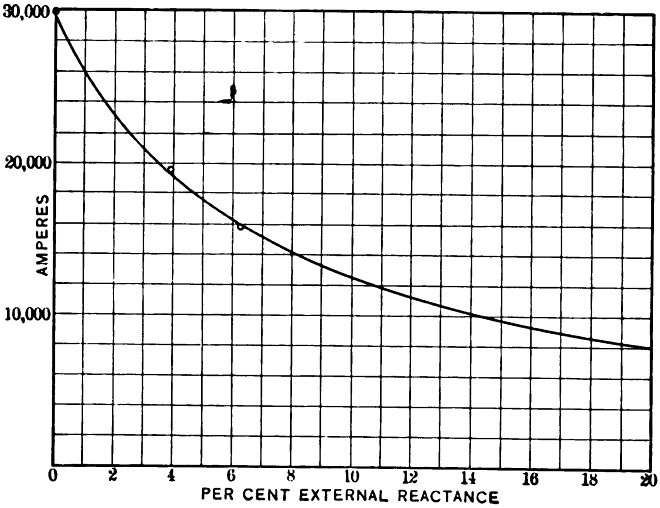

FIG. 5.—MAXIMUM INITIAL PEAK VALUES OF CURRENT THROUGH 12,000-KW. ALTERNATOR AT 9,000 VOLTS ON EXTERNAL THREE-PHASE SHORT CIRCUITS OF ZERO RESISTANCE AND VARIOUS REACTANCES.

If the resistance is not negligible the analytical solution of equation (**6**) for maximum i becomes difficult and the investigation is carried out most readily by plotting various families of curves. For this purpose the variables of equation (**6**) may be grouped,

$$Y = \cos\left[\theta - (\theta_0 + \theta_1)\right] - \epsilon^{-\frac{r}{x}\theta}\cos(\theta_0 + \theta_1) \qquad \textbf{(10)}$$

and θ, $\frac{r}{x}$ and $\theta_0 + \theta_1$ considered the new variables.

Taking $\theta_0 + \theta_1 = \pi$ the family of curves given in Fig. 6 is obtained, showing the values of (**10**) for representative values of $\frac{r}{x}$ and all values of θ from 0 deg. to 180 deg. Similar families have been plotted for other values of $\theta_0 + \theta_1$ and the maxima of each of the several series made up of those curves having the same value of $\frac{r}{x}$ but different values of $\theta_0 + \theta_1$ are combined in Fig. 7 to form one of a new family of curves in which, therefore, for each value of $\theta_0 + \theta_1$ and $\frac{r}{x}$, θ has the value shown by Fig. 6 and the similar families to be necessary to make (**10**) a maximum.

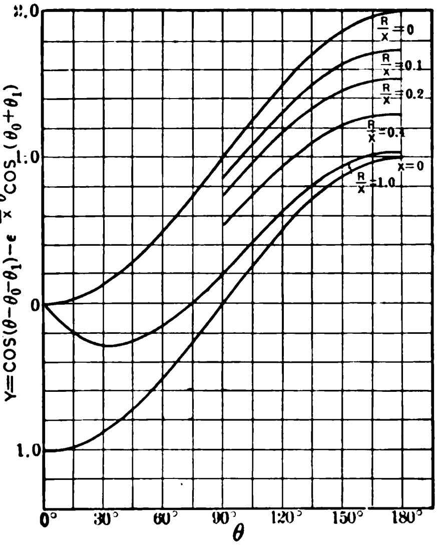

FIG. 6.—VALUES OF Y, EQUATION (**10**), FOR REPRESENTATIVE VALUES OF $\frac{r}{x}$ AND ALL VALUES OF θ FROM 0 TO π WHEN $\theta_0 + \theta_1 = \pi$.

The dotted line drawn through the peak of these last curves is found to pass through the points corresponding to $\theta_0 = \frac{\pi}{2}$

and it is apparent, therefore, that under all circuit conditions the maximum current is obtained when the short circuit occurs at the zero value of the corresponding e.m.f. wave.* From Fig. 7 too, it is seen that the maximum value of (**10**) for any value of $\theta_0 + \theta_1$, is in no case more than 2.5 per cent greater than that obtained for $\theta_0 + \theta_1 = \pi$ and as, when $\theta_0 + \theta_1$ is made equal to π, the maximum value shown by Fig. 6 for any value of θ is not more than 0.5 per cent greater than the corresponding value when $\theta = \pi$ by taking both $\theta_0 + \theta_1$ and θ equal to π we may obtain a simplification of equation (**6**) which will result in values of $I_m{}^0$ within 2 per cent or 3 per cent of the absolute maximum. So simplified,

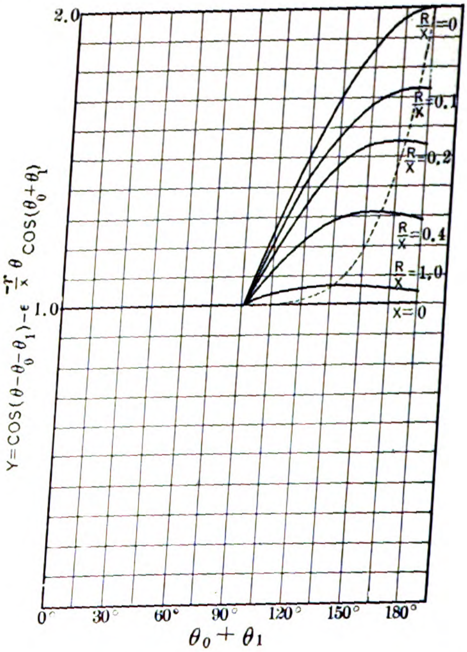

FIG. 7.—VALUES OF Y, EQUATION (**10**), FOR ALL VALUES OF $\theta_0 + \theta_1$ FROM $\frac{\pi}{2}$ TO π, AND A REPRESENTATIVE VALUE OF $\frac{r}{x}$ WHEN θ HAS SUCH A VALUE AS TO MAKE Y A MAXIMUM.

$$I_m{}^0 = \frac{E_m{}^0}{z}\left(1 + \epsilon^{-\frac{r}{x}\pi}\right) \qquad (\mathbf{11})$$

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*An analytical demonstration of this fact is given in Appendix A.

gives the approximate maximum of the maximum phase, the minimum initial peak of the minimum phase being given by,

$$I_m^{0\prime} = \frac{E_m^0}{z} \tag{12}$$

Applying (**11**) and (**12**) to the 12,000-kw. generator with no external reactance the upper double branched curve of Fig. 8 results, the two branches showing the decrease in the range of possible values for the initial peaks of the three phases as the resistance of the short circuit is increased.

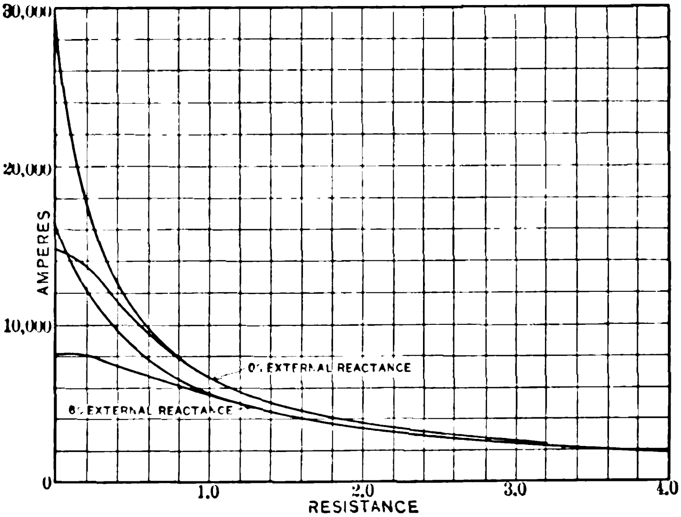

Fig. 8.—Limits of Current through Short Circuits of Various Resistances, Supplied by a 12,000-kw. Alternator.

Both when the unit is protected by 6 per cent reactance coils and when it is connected directly.

It is noteworthy that a resistance of one ohm per phase eliminates the transient term entirely both for this curve and the lower double branched curve showing similar values when 6 per cent external reactance coils are included in the circuit. That is, for resistance greater than 0.8 or 1.0 ohm all three phases have equal initial peaks or we have a simple a–c. phenomenon. As the unit is earthed through a 2.5-ohm neutral rheostat, cable breakdowns or faults from phase to sheath are thus purely a–c. phenomena, and from the closeness of the upper and lower curves of Fig. 8 at the 2.5–ohm point, are unaffected by any practicable amount of external reactance.

(*b*) *The Maximum and Minimum Currents into Various Classes of Faults from a System Operating Several* 12,000-*kw. Units in Parallel.*

With n units in parallel feeding a short beyond the station bus bars, equations (**11**) and (**12**) take the forms,

$$I_m^0 = \frac{E_m^0}{\sqrt{\left(r_{ext} + \frac{r_T}{n}\right)^2 + \left(\frac{x}{n}\right)^2}} \left[1 + \epsilon^{-\left(\frac{n\, r_{ext} + r_T}{x}\right)\pi}\right] \qquad (13)$$

and

$$I_m^{0\prime} = \frac{E_m^0}{\sqrt{\left(r_{ext} + \frac{r_T}{n}\right)^2 + \left(\frac{x}{n}\right)^2}} \qquad (14)$$

The assumption that the transient resistance term is negligible as compared with the external resistance, however, becomes more nearly true as n increases so that for several units these equations may be simplified as

$$I_m^0 = \frac{E_m^0}{\sqrt{r_{ext}^2 + \left(\frac{x}{n}\right)^2}} \left[1 + \epsilon^{-\frac{n\, r_{ext}}{x}\pi}\right] \qquad (15)$$

and

$$I_m^{0\prime} = \frac{E_m^0}{\sqrt{r_{ext}^2 + \left(\frac{x}{n}\right)^2}} \qquad (16)$$

From these latter equations the curves of Fig. 9 for five 12,000-kw. units in parallel are plotted similarly to those given in Fig. 8 for a single unit. With a three-phase short circuit on a standard 250,000–cir. mil cable fed from a five-unit system, if the breakdown is a mile or more from the station, the decrease in current due to 6 per cent external reactance coils is negligible and no transient term occurs, this critical distance being one-fifth that which obtains for a single unit. But for an appreciable resistance the three-phase short-circuit current of five units is considerably less than five times that of a single unit, so that although up to about two ohms per phase resistance those effects of a breakdown which depend only on the amount of current, increase in severity at the fault and in the feeder switch with the number of units in service, the effect on the individual units decreases as more units are operated in parallel. The application of these statements to a breakdown from phase to ground depends on the scheme followed in operation. If, as is usual, a single unit is earthed that unit takes the entire short circuit current and this is practically independent of the number of units on the bus. If, however, all units are connected to a neutral bus which is earthed through a neutral rheostat the total short circuit current will be independent of the number of units and the strain per unit inversely as this number.

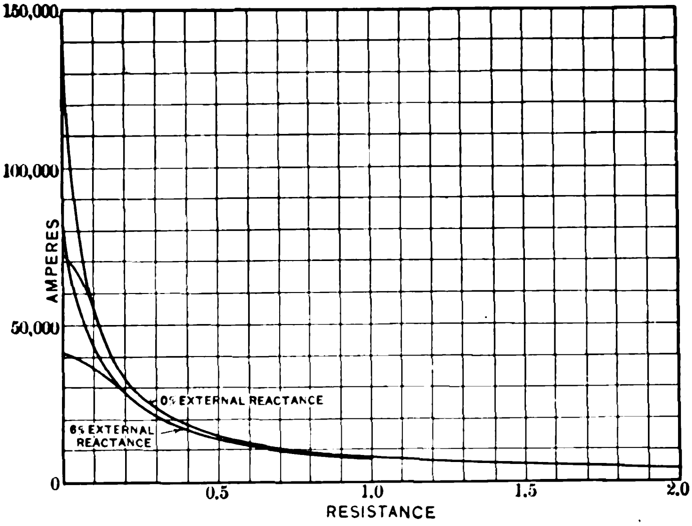

Fig. 9.—Limits of Total Current through Short Circuits of Various Resistances Supplied by Five 12,000-kw. Alternators in Parallel.

With and without the protection of 6 per cent external reactance coils on each circuit.

(*c*) *The Maximum Cross Currents Obtainable when Paralleling a 12,000-kw. Generator to a System Operating several such Units in Parallel.*

As a special case of the the parallel operation of units we may consider the cross currents flowing when an additional unit is connected to a bus supplied by n similar units. Here r_{ext} is zero, r_T is negligible and the e.m.f., assuming the pressure of the incoming unit to be equal to that of the bus, is twice the bus pressure, multiplied by the sine of one-half the phase angle between bus and the incoming unit. Taking the worst case, when the unit is thrown in 180 deg. out of phase and the switch closed at the zero value of the pressure waves,

$$I_m^0 = \frac{2\,(2\,E_m^0)}{x + \dfrac{x}{n}} \tag{17}$$

and the numerical values applying to the system under discussion for external reactances from 0 to 10 per cent and n from 1 to ∞ are shown in Fig. 10.

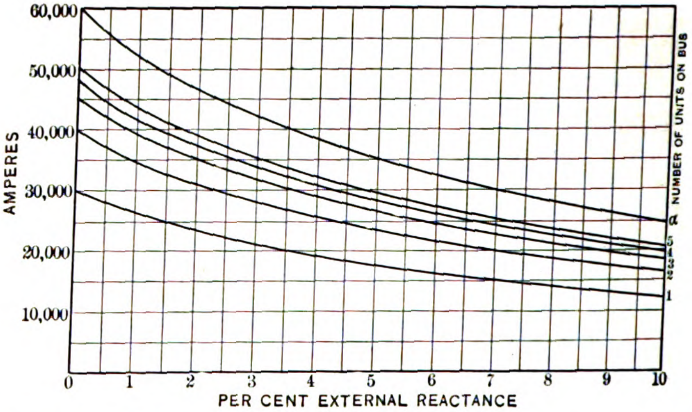

FIG. 10.—MAXIMUM INITIAL PEAK VALUES OF CURRENT WHEN A SINGLE 12,000-kw. UNIT IS CONNECTED 180 DEG. OUT OF PHASE TO A BUS SUPPLIED BY ANY NUMBER OF SIMILAR UNITS.

Each unit equipped with external coils having from 0 per cent to 10 per cent reactance.

At the Fisk Street station with four units previously operating, the 6.3 per cent reactances installed would only limit current to 26,000 amperes in the worst case of synchronizing. This, while little more than half that obtained with no external reactances, is still probably quite sufficient to wreck the incoming unit. Although, therefore, reactance offers considerable protection against poor synchronizing no amount considered in any of the. installations yet made will give complete security.

(d) The Instantaneous Torque Developed by the Maximum Short Circuit Currents of (a) and (b).

Applying the conception of transient impedance to the investigation of the maximum instantaneous torque which tends to twist or spring the shaft or to strain the entire armature of a short circuited alternator, we obtain the very simple formula,

$$W_m{}^0 = \frac{3}{2}\,\frac{(E_m{}^0)^2}{z^2}\,r\left(1 + \epsilon^{-\frac{r}{x}\pi}\right)^2 \tag{18}$$

For when $r = r_T + r_{ext}$ the torque is evidently the sum of the i^2r losses for the three phases and in a three-phase short through any reasonable amount of external resistance r_T may be taken as equal in each phase, making,

$$\begin{aligned} w^0 = \frac{(E_m{}^0)^2}{z^2}\,r\,\Bigg\{&\Big[\cos(\theta-\theta_0-\theta_1) - \epsilon^{-\frac{r}{x}\theta}\cos(\theta_0+\theta_1)\Big]^2 \\ &+\left[\cos\left(\theta-\theta_0-\theta_1-\frac{2\pi}{3}\right) - \epsilon^{-\frac{r}{x}\theta}\cos\left(\theta_0+\theta_1+\frac{2\pi}{3}\right)\right]^2 \\ &+\left[\cos\left(\theta-\theta_0-\theta_1-\frac{4\pi}{3}\right) - \epsilon^{-\frac{r}{x}\theta}\cos\left(\theta_0+\theta_1+\frac{4\pi}{3}\right)\right]^2\Bigg\} \end{aligned} \tag{19}$$

Expanding these expressions and reducing by the formulas given by Dr. Steinmetz in *Engineering Mathematics*, page 105.

$$w^0 = \frac{3}{2}\,\frac{(E_m{}^0)^2}{z^2}\,r\left[\left(\cos\theta - \epsilon^{-\frac{r}{x}\theta}\right)^2 + \sin^2\theta\right] \tag{20}$$

This expression does not contain θ_0 or, in other words, the torque is entirely independent of the point of the pressure wave at which the short circuit occurs. Furthermore the transient term becomes practically negligible for $\frac{r}{x}$ = or > 4 and **(20)** then reduces to

$$w^0 = \frac{3}{2}\,\frac{(E_m{}^0)^2}{z^2}\,r = 3\,E\,I\cos\theta_1$$

the fundamental power equation of the three-phase circuit. To obtain $W_m{}^0$ the latter part of **(20)**

$$\left(\cos\theta - \epsilon^{-\frac{r}{x}\theta}\right)^2 + \sin^2\theta$$

may be investigated graphically as is done in Fig. 11 where the solid lines represent the values of the expression for various values of $\frac{r}{x}$ from 0 to ∞ the dotted lines showing the component terms for $\frac{r}{x} = 0.2$. Here again as in the case of the current curves of Figs. 6 and 7 the peaks are so flat that the absolute

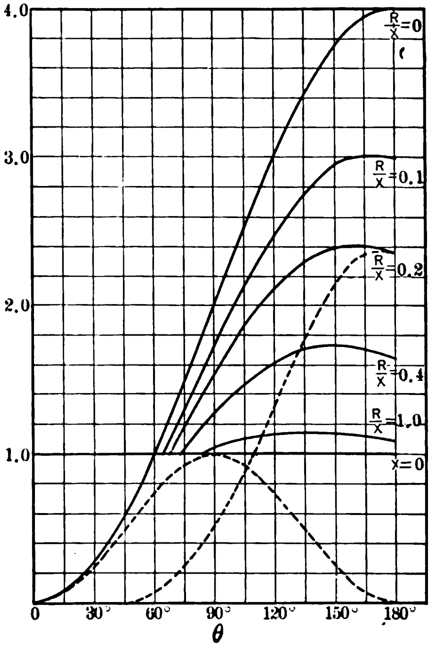

FIG. 11.—VALUES OF $\left(\cos\theta - \epsilon^{\frac{-r}{x}\theta}\right)^2 + \sin^2\theta$, EQUATION (**20**), FOR REPRESENTATIVE VALUES OF $\frac{r}{x}$ AND ALL VALUES OF θ FROM 0 TO π.

maximum torque is never more than 4.5 % greater than the torque for $\theta = \pi$ and hence, for all practical purposes (**20**) may be written as in (**18**). It is interesting to observe that this equation can be derived from the three-phase power equation written in the form $W = \frac{3}{2} I_m{}^2 r$ by substituting the approximate value of $I_m{}^0$ given in (**11**). That is, the maximum transient torque is the same as the constant torque of a three-phase circuit in which the I_m of the sine current equals the maximum possible peak of the maximum phase under short circuit.

Using in equation (**18**) the values of x for the 12,000-kw. alternator, the curves of Fig. 12 are obtained, showing the decrease of torque with increase of resistance. For any given resistance the decrease due to the addition of 6 per cent external reactance is equal to the difference in ordinates of the upper and lower curves and is directly proportional to the decrease in the square of the current. The end turn stresses in the armature winding are also proportional to the square of the current so that in any specific short circuit all stresses on the alternator are reduced in the same ratio by additional reactances. But the maximum possible end turn and torque stresses do not occur simultaneously, for the maximum current flows with minimum transient impedance, or in a zero resistance bus short circuit, while the maximum torque results when some considerable resistance—the exact value depending on the simultaneous value of the reactance—is in circuit. In the case considered in Fig. 12 the possible maximum torque is thus reduced only 45 per cent by 6 per cent reactances or directly as the maximum current. This variation of the maximum possible torque in direct proportion to the short circuit current at zero resistance as suggested by the last statement, or in other words, a variation of the maximum torque inversely as the total reactance x

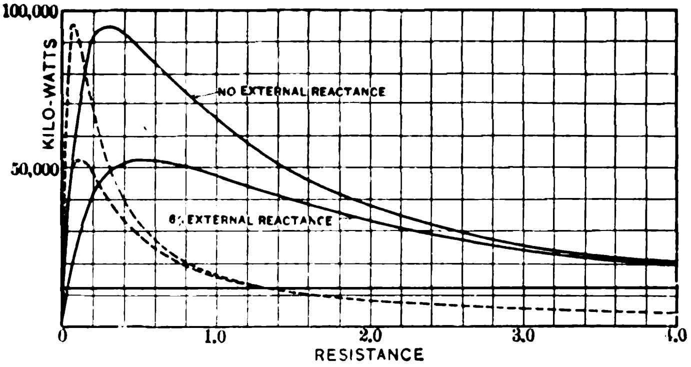

Fig. 12.—Maximum Instantaneous Torque Developed in a 12,000-kw. Alternator when Subjected to External Short Circuits of Various Resistances and of Zero or 6 per cent Reactance.
- - - Each of five units in parallel. ——— — Single unit system.

so that maximum $W_m^0 = \frac{K}{x}$, is found empirically to be a true property of equation (**18**) by plotting curves as in Fig. 12 for other values of x. The current curves of Fig. 5 may thus be redrawn to show the percentage decrease in possible maximum torque as well as in short circuit current, secured by the use of various external reactance, as is done in the upper curve of Fig. 13. The lower curve of this figure showing the corresponding decrease in end turn stresses is plotted to the same scale but the great difference in the actual magnitudes of the end turn and torque stresses must be kept in mind. Thus, with no external reactance the torque is 7.9 times, the short circuit current 27 times, and the end turn stresses 729 times, the magnitudes existing at full load. Hence, although the end turn stresses are reduced 69 per cent by 6 per cent reactance coils, and the torque but 45 per cent, the torque is 4.3 times full load, while the end turn stresses are still 226 times normal. Indeed, even 20 per cent reactance coils leave the end turn stresses 58 times normal.

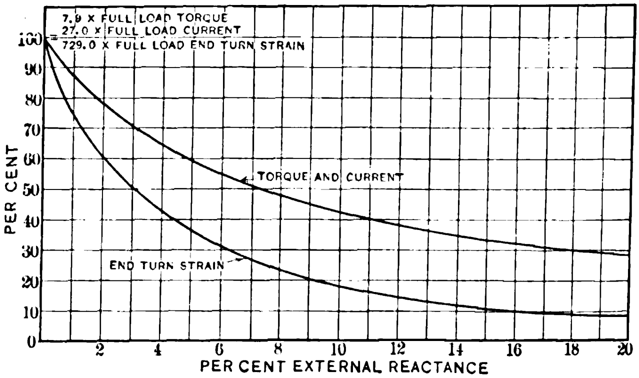

FIG. 13.—MAXIMUM SHORT-CIRCUIT CURRENT, MAXIMUM TORQUE AND MAXIMUM END-TURN STRESSES IN A 12,000-KW. ALTERNATOR, UNDER SHORT CIRCUITS OF VARIOUS EXTERNAL REACTANCES.

Plotted in percentage of values without external reactance.

As, however, external reactances have a large percentage effect in reducing end turn stresses, the introduction of reactance coils evidently gives great protection to end turns even though still leaving these stresses large, but in lessening mechanical shock and retardation of the generator the percentage effect is considerably smaller and thus the protection much less than has been claimed.

With n units in parallel supplying a short circuit of fixed resistance the torque on each unit is equal to that produced in a single unit short circuited through n times the given resistance. The lower dotted curve of Fig. 12 thus shows the torque on each of five machines protected by individual 6 per cent reactance coils and short circuited through various external resistances (the upper dotted curve showing similar relations for five units without reactance coils). Comparing the corresponding curves for one and five units it is seen that the answer to the question as to whether a unit will receive a more severe shock on a short circuit when it is operating alone or in parallel with other units depends entirely on the particular short circuit conditions. For station short circuits, including cable breakdowns within a short distance of the station, the blow per machine will be much more severe with five units than with one, while the total power to be interrupted with five units—given by five times the ordinates of the dotted curves may reach 265 megawatts with 6 per cent reactance coils as against the 53 megawatts which can be supplied by one unit. For short circuits of more than 0.25 ohms resistance the blow per machine with five units in parallel rapidly becomes less than that with a single unit reaching full load torque for a short circuit of 1.4 ohms at which point a single protected unit would experience a torque 3.5 times full load. With resistances of three or four ohms per phase, magnitudes, that is, corresponding to substation short circuits, the total power to be interrupted, which has now decreased to about 20 megawatts is practically the same with five units as with one, and the blow per machine with three or more units in parallel is hardly more than may be met in normal operation.

In review it will be noted that all the conclusions of this paper are based on two assumptions; first, that the transient reactance is constant at and near the middle of the first cycle; and second, that when this reactance is introduced in equation (6), true current values are obtained at and near $\theta = \pi$. The first of these assumptions is discussed under the heading Transient Impedance. The second remains to be validated. The dotted curves of Fig. 14 represent the simultaneous three-phase current waves taken from oscillograms No. 317 and No. 318 made in test No. 190—a three-phase short circuit at 9,000 volts Δ with 6.3 per cent external reactance coils. Considerable discrepancies, due to the oscillograph, to current transformer distortion, or to other errors in measurement exist in one or all of these wave forms, as is shown by the dashed curve which represents the sum of the dotted curves for *A* and *B* phases and should, therefore, coincide with the dotted or oscillograph curve for *C* phase, and these discrepancies must be remembered in judging the agreement between the oscillograms and the theory. From the oscillogram of the generator pressure—a curve not shown in the figure—θ_0 for *A* phase is found by actual measurement to be—72 deg. and substituting this figure and appropriate figures for *B* and *C* phases in equation (7), r being assumed negligible and $x = 0.924$ ohms, the full line curves of Fig. 14 are

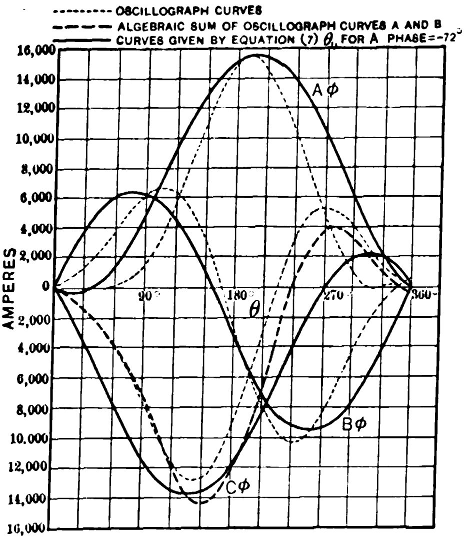

Fig. 14.—Agreement of Equation (7) with Oscillograms.

obtained. A considerably better agreement may be secured by trial, using various values of r but at the 180-deg. point the coincidence shown in the figure appears quite sufficient for all practical applications of the work.

These curves are fairly typical of all those investigated and, although the variations of the oscillograms from the mathematical curves show that the reactions are much too complex to be perfectly represented by a simple law of variation for the transient reactance, it is believed that the two main assumptions of this paper give a practical means of closely predicting from a single low-voltage short circuit test the transient reactions of an alternator.

APPENDIX A

To demonstrate that the equation

$$i = \frac{E_m^0}{z}\left\{\cos(\theta-\theta_0-\theta_1)-\epsilon^{-\frac{r}{x}\theta}\cos(\theta_0+\theta_1)\right\}$$

gives the maximum value of i when $\theta_0 = \frac{\pi}{2}$ or when the circuit is closed on the zero point of the e.m.f. wave for all values of r and x. Let $\frac{r}{x} = \cot\theta_1 = K$ a constant in any specific case.

As θ and θ_0 are independent variables the expression is a maximum when $\frac{d\,i}{d\,\theta}$ and $\frac{d\,i}{d\,\theta_0}$ are both equal to zero, but

$$\frac{d\,i}{d\,\theta_0} = \cos\theta_0\sin\theta_1\left\{\tan\theta_0\left[K\,\epsilon^{-K\theta}-K\cos\theta-\sin\theta\right] + \left[\epsilon^{-K\theta}-\cos\theta+K\sin\theta\right]\right\}$$

and ∴ when

$$\frac{d\,i}{d\,\theta_0} = O,\ \tan\theta_0 = \frac{-\epsilon^{-K\theta}+\cos\theta-K\sin\theta}{K\,\epsilon^{-K\theta}-K\cos\theta-\sin\theta}$$

also

$$\frac{d\,i}{d\,\theta} = \left[\frac{-\cos(\theta_0+\theta_1)}{K-\tan\theta_0}\right]\left\{\tan\theta_0\left[K\,\epsilon^{-K\theta}-K\cos\theta-\sin\theta\right] - \left[-K^2\,\epsilon^{-K\theta}-\cos\theta+K\sin\theta\right]\right\}$$

and ∴ when

$$\frac{d\,i}{d\,\theta} = O\ \tan\theta_0 = \frac{K^2\,\epsilon^{-K\theta}+\cos\theta-K\sin\theta}{K\,\epsilon^{-K\theta}-K\cos\theta-\sin\theta}$$

Hence for the maximum value of i

$$\tan \theta_0 = \frac{-\epsilon^{-K\theta}+\cos\theta-K\sin\theta}{K\epsilon^{-K\theta}-K\cos\theta-\sin\theta} = \frac{K^2\epsilon^{-K\theta}+\cos\theta-K\sin\theta}{K\epsilon^{-K\theta}-K\cos\theta-\sin\theta}$$

This is only possible for real finite values of K and θ when

$$K\epsilon^{-K\theta} - K\cos\theta - \sin\theta = 0$$

or when

$$\tan\theta_0 = \infty$$

and

$$\theta_0 = \frac{\pi}{2}$$

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VACUA

BY W. R. WHITNEY

The purpose of this article is to publish a few observations made in the research laboratory on some phenomena in vacua, as they may possibly be of interest to others who are working in the field of evacuated apparatus.

The subject has a double interest because at first glance it seems difficult to see how there can be much ground for study, or material and phenomena for useful investigation in such an apparently confined *volume* of nothingness as the vacuum of an incandescent lamp. The many actual developments from this lack of material are interesting, and there is the added interest, due to the fact that there are to be found in these lamps examples of many of the phenomena of gaseous ions which are receiving so much study in our day.

It has long been known that the life of an incandescent lamp is greatly influenced by the quality of its vacuum. In general, one may say that the better the vacuum, at least up to a certain point and until recently, the longer the life of the lamp. In the early days of lamp making, many schemes were devised to improve the vacua. This was then all the more necessary, as the mechanical methods of lamp-exhausting were very much inferior to present ones. The harmful effects of oxygen and water vapor, both of which reacted upon the filaments, were well known and many ways were devised for removing them.

What seems to be an especially interesting method of supplementing the vacuum pumps was the method of Malignani. This process, in its most perfect form, consisted in distilling into the bulb a small amount of some such substance as arsenic, sulphur, iodine, or phosphorus. At the instant when one of these vapors was introduced, he passed a high current through the filament, the lamp being closed from the pump. This has long been the common commercial process for lamps which are to operate on voltages above 50, and many millions of lamps have been exhausted by its aid.

In case of incandescent lamps where the voltage is above 50 for a fair brilliancy of filament, a blue discharge passes through the bulb and this blue quickly disappears when such vapors are introduced. The blue discharge seemed to be necessary for any considerable improvement of the vacuum, due to such vapors as phosphorus, and this led to the assumption that the gases still left in the lamp by the pump, were removed quickly during the blue glow and probably by the vapors which were at the same time being deposited on the glass. Although the facts were pretty well known, we performed experiments to study the phenomena. It was found that when the vacuum was measured by a McLeod gage, the sudden marked improvement of vacuum was easily proven. For example, in experiments carried on by Mr. Willey, of the laboratory, when the pump had produced a vacuum of 0.030 mm. mercury and the cock leading to it was closed, a trace of phosphorus was distilled into the bulb while the filament was very hot and a blue glow had appeared; then about as quickly as the gage could be read the pressure had fallen to 0.002 or 0.001 mm.

That this improvement of vacuum is quite commonly produced when vapors of any kind are caused to condense in the space is not new. It even takes place markedly when the filament is first heated to very high temperature without added vapor, and a *blue glow* also passes through the lamp at the time. In improving the vacuum this latter way, however, it is known that the filament is injured and apparently a part of its material has been vaporized. This process soon causes blackening of the bulb by carbon.

This vaporization of phosphorus into the lamp at the moment when the pump has done its work, has long been the commercial method of finishing the exhaustion of incandescent lamps. The fact that even the carbon alone tended to the same end, though at the expense of the filament, being recognized, it became of interest to get a clearer view of this phenomenon.

In other words, if an incandescent lamp was burned while connected to a McLeod gage and the vacuum became poorer, the changes of vacuum might be measured by the gage from time to time. If, on the other hand, the vacuum improved so that the pressure tended to become less than the vapor pressure of mercury at the temperature of the gage, then the gage would not only not measure it, but the mercury vapor might even have affected the life of the lamp. When experiments were made to determine the effect of the vapor of mercury at the low pressures corresponding to a micron, which is the vapor pressure of mercury at 15 deg. cent., very peculiar results were obtained and the lamps showed very early blackening. It looked as though even the presence of this constant mercury pressure was fatal to the lamp. Therefore the discovery of a more practical vacuum gage was desirable.

Without committing ourselves to a theory, we can describe one or two interesting experiments with mercury vapor. It was first discovered that an incandescent lamp grew black very quickly when attached to a mercury column which served as a gage to indicate evolution of gas. No such combination could be made to last over a few hours. The lamp blackened just as though it was in an imperfect vacuum. It is hard to see how the mercury can have any chemical effect upon the filament as oxygen or water have, and the effect is common to carbon and tungsten lamps. Many lamps were then made which were exhausted as perfect lamps are exhausted, except that a small quantity of mercury was left in the bulb. It was assumed that this would not interfere with the removal of air and moisture and might even assist by the washing effect of the mercury vapor, mechanically removing air. Lamps were also made in which a large quantity of mercury was placed, the lamp put into an oven above the boiling-point of mercury and the air washed out by the distilling mercury no pump being used. When the mercury was nearly all removed the bulb was sealed off. This method, if no visible mercury is left in the bulb, is capable of giving good lamps, but where a visible drop of mercury was present the lamp would show a persistent blue glow and rapidly blacken, even below its normal voltage. In some cases it would arc between the leads, exactly as in the case of poorly exhausted lamps.

Lamps were also made to which were attached tubes which carried small globules of mercury. When these side tubes were short and straight, such as one or two inches, and the lamp was exhausted as well as possible on the pump, the blackening of the bulb started at once when the entire glass was at ordinary temperature. If now, the side tube with its mercury was submerged in different cooling mixtures, the length of time for a given blackening was increased. For example, at room temperature the lamp would be blackened so as to correspond to 80 per cent of its original candle-power in a few minutes. When the side tube containing the mercury was at 0 deg. cent. this time became two or three hours; and when cooled in a freezing mixture at 20 deg. cent. the life to 80 per cent was over 75 hours. Such differences were also noted when the pressure of mercury vapor was controlled by using different cadmium amalgams, the amalgams higher in mercury corresponding to the shorter lamp life.

It was interesting to note also that by lengthening the side tube containing the mercury, the rate at which this deposition of filament material in the bulb was decreased.

In a set of experiments at ordinary temperatures the length of the side tube was increased and it was wound as a spiral. This reduced the rate at which the mercury could reach the bulb proper. In this case, instead of there being a continuous faint blue glow, as there is when the mercury is in a short side tube, the blue glow appeared and disappeared continuously and regularly It looked as though there was a certain pressure of the vapor necessary before the blue discharge could occur and that when this was reached, the sudden discharge produced the blue and cleared the vacuum to a much lower pressure. Then mercury vapor distilled anew from the long side tube until again the necessary pressure was reached, when the process of clean-up repeated itself.

If the lamp bulb was kept very hot, the blackening was reduced and even done away with altogether, as though the deposition of the mercury vapor upon the glass by the discharge signalized by the blue glow could not take place. If, however, water vapor was present, even in very small amount, the blackening would take place very rapidly, even in the absence of mercury. In other words, most ordinarily exhausted lamps will blacken relatively quickly if allowed to burn in a heated oven. In general, the hotter the oven the more rapid the blackening, but this process is largely, if not entirely due to imperfect exhaustion. All glass contains water which can be removed but slowly, even at relatively high temperatures. It has even been found that indefinite heating of a lamp connected to the vacuum pump is not capable of removal of all of this water. If exhaustion be carried on for a very long time at room temperature, then merely raising the temperature will cause liberation of more gas and after heating and exhausting to an equilibrium condition at say 200 deg.cent. more water will be produced on heating to 300 deg. cent. and still more at 400 deg. For this reason it is customary to exhaust at as high a temperature as possible. At 400 deg. cent. the ordinary glass has reached its limit, owing to the proximity of the softening point. For this reason we have had to exhaust the oven in which the lamps were being exhausted, in order to study the water evolution at higher temperatures.

For a long time it was impossible to follow the change of vacuum in a lamp, because the pressure could very evidently not be reduced below the vapor pressure of the mercury of the McLeod gage attached to the lamp. It has long been known also, that the current passed through the space of the bulb to a considerable extent, and that this varied with the degree of vacuum, etc. A very complete discussion and description of experiments on this so-called Edison effect are given by Professor Fleming, in Vol. 42 of the *Philosophical Magazine.* In general, the conclusions are that in the vacuum of an incandescent lamp a current can flow across the space from the negative end of the filament to any conductor in the bulb, if this be so located that particles passing in straight line from the negative leg may come into contact with this conductor. This latter was usually a small platinum plate, and to it, as anode, a continuous current flowed from the negative half, or end of the filament, except when it was intermittently shielded from direct emanations. The current often of several milliamperes was measured by a galvanometer connected between the metal plate and the positive terminal of the lamp. It is known that the materials of the filaments distill in straight lines and cast well defined shadows, because the mean free path at this pressure is greater than the diameter of the bulb, and it was natural to assume that this vaporizing carbon carried electric charges of negative sign. This assumption might seem to acquire the more rapid wasting away of the negative half of the filament than the positive, but no data are present to prove this. When condenser charges were superposed on this apparatus it was found that with the negative end connected with the negative side of the condenser, the condenser was at once discharged. When connected oppositely, it was not discharged. Current could pass as negative from the hot conductor or filament, but not from the cold plate, nor could positive current pass from either the hot or cold terminal.

In connection with this work of Fleming's, we have studied the effect of the condition of vacuum on the current, and also found that the presence of gas is necessary for this negative discharge. In general, the higher the pressure of the gas when this does not exceed a few thousandths of a millimeter mercury, the greater is the current. This makes it seem improbable that the current is solely dependent on the passage of carbon or tungsten from the filament to the positive electrode. though it leaves the possibility open that the current may be carried by gaseous ions produced by negatively charged material coming from the negatively charged filament.

By using alternating current and a metal electrode in a carbon lamp, Fleming obtained direct current on the circuit connecting the metal plate to either terminal of the lamp and the current was in the direction expected, the plate being negative to the terminal.

This outfit is thus obviously a rectifier, and it has been so used by Fleming for low currents.

The effect of a magnetic field on this gaseous conduction, just as in the case of metallic bismuth, is to increase the resistance.

It was finally found that the Crookes radiometer was a very sensitive gage for the changes of pressure in lamps, and by its use the changes could be followed in a qualitative manner, even throughout the life of the lamp, by having the radiometer sealed directly to the lamp. Dewar has shown the sensitiveness of this apparatus in the *Proc. Roy. Soc.*, 1907, 531.

The radiometer consists of a glass bulb containing a perpendicular needle with a glass cap on which is four aluminum arms with a mica vane at the end of each. One face of each mica vane is coated with lamp-black. When the radiometer is evacuated to a high degree, the effect of radiant energy or light is to cause rotation, which is believed to be due to the fact that the molecules of gas take up energy from the blackened surface of the vanes more than from the plane surfaces, the black absorbing more of the incident energy and thus locally heating the gas molecules. These in the rarefied atmosphere largely give off this energy to the walls of the apparatus by direct impact, rather than to other molecules in the neighborhood of the vane. This results in a motion of the vane opposite to the motion of the gas molecules, because the unblackened face of the vane receives impact mostly from these cooler molecules.

The vacuum of the lamp as sealed from the pump approximates a few microns and is poor enough so that the radiometer rotates rapidly when exposed to light. By using a fairly constant light intensity and noting its effect upon a radiometer attached to a lamp which was lighted for intervals, it was seen that the radiometer gradually rotated slower and slower, and finally after a period of normal lamp brilliancy of from 12 to 36 hours on tungsten lamps, it would stop rotating altogether. At this point it was found that a more sensitive measure of still higher vacua could be gained by starting in the dark by mechanical motion a rotation of the vanes of a definite speed, and noting the rate of speed decay on standing. This was done by proper spinning of the whole apparatus in the hand and then getting the rate of decrease in this rotation of the vanes by counting definite revolutions after definite time intervals. Here the friction of the residual gases was merely overcoming the momentum imparted mechanically to the vanes at start. In this way, even by comparing the minutes required for the radiometer to come to a stop, quite interesting information was obtained.

This method was not developed into a quantitative one, though it might have been. The radiometer method shows us, however, some interesting facts which are worth describing. Using the common type of radiometer often seen in jewellers windows and sealing this directly to a lamp made from 110 volt circuit, the radiometer would rotate when in daylight. This showed the presence of some gas in the lamp and the McLeod gage used at the time of sealing the lamp from the pump showed approximately 2 microns. If, now, the radiometer and the lamp were removed to a dark room and a rotating motion imparted to the vanes, they would proceed to rotate for about a minute, this time depending somewhat on the particular radiometer used, as well as on the condition of the vacuum.

Since at the moment when the filament was at bright heat and the vacuum very poor (so poor, in fact, that if the pressure were maintained constant the lamp would blacken in a few minutes), the vacuum greatly improved, due to some action occurring together with spattering of the filament, it seemed important to know more about the phenomena. We assume that the gas at first present goes to the walls of the lamp and is held there, possibly absorbed by the small quantity of deposited filament material. It is always possible to drive the greater part of it back into the vacuum space by warming the glass. It seemed perfectly possible that the process might be a cyclic one; that is, the gas carrying to the walls of the bulb some of the filament material and not of necessity remaining there, but possibly returning for a fresh supply. This continued process might account for the limited life of an incandescent lamp. It did not seem necessary to assume that there was any measurable rate of simple distillation from a carbon filament at the temperature of operation, though such a phenomenon could account for limited life of filament. It even seemed possible that the cyclic process, instead of being physical, might well be expressed as a chemical one, such as we know could exist, and might continue between the oxides of carbon and carbon itself. At the high temperature of the filament carbon monoxide would be expected but this, at a lower temperature, would form CO_2 and free carbon, the latter being deposited upon the glass. The free CO_2 coming into contact with the hot carbon filament would again form carbon monoxide, and thus the process be repeated continuously until the filament was burned through or the lamp became too black to be of use. It was therefore desirable to get a closer insight into the phenomena in the lamp at a few microns pressure.

Similar considerations can apply equally well to the case of tungsten filament lamps. In the case of osmium lamps this reasoning extended, explains the fact that the presence of a little oxygen in the lamp was necessary to prevent blackening of the bulb by the deposited metal. A little oxygen in a carbon lamp might similarly remove deposited carbon from the glass and deposit it upon the filament, if the temperature at the two points were suitable, but with this element it seems impracticable because the oxide formed is not easily reduced below the CO state, thus differing from osmium.

While the lamp to which a radiometer was attached was not lighted, practically no change in vacuum could be detected by the radiometer. Therefore there is no leak of air from without. If, however, the lamp was lighted, the reverse was true. On allowing the lamp to be lighted for a few seconds only, and then cooling and testing in the dark room as before, the duration of rotation would usually be shorter, thus indicating a liberation of gas into the bulb space by this short time of burning. If, however, the lamp were allowed to burn at a normal brilliancy for a longer time and the same vacuum test was made from time to time on the unlighted lamp in the dark room, it was found that the duration of the impressed rotation rapidly increased. In many cases a rotation lasting 15 minutes would be produced by allowing the lamp to burn 24 hours. This phenomena of automatic vacuum improvement received the name of the "clean-up." While the clean-up, as measured in in this rough way, did not seem to take place in all lamps to the same degree, it was always present under ordinary conditions.

Other types of vacuum lamps improved their vacua on running. In fact, no lamp, unless we except the mercury arc, fails to do so. The well-known Moore tubular system of lighting, which is a development of the Crookes tube, consumes the gas, and for that reason an automatic valve was invented which supplies air to the tube when the vacuum improves to a certain point. It is also an old story, in the case of the cathode and X-ray tubes. X-ray tubes are usually made with a salt, such as potassium chlorate or potassium hydrate, mica, asbestos, etc., in an attached side tube. This may be heated when the tube in use attains too high degree of evacuation, and in this way gas is liberated into the bulb. This is in turn removed from the vacuous space by the operation of the tube. A natural question is raised at once: what becomes of these disappearing gases? In some cases they are probably forced or shot into the glass itself, for some of these old glasses bubble on being heated to the softening point. Possibly the greater part of the gas is absorbed by the exceedingly finely divided metal, which slowly deposits on the glass as it vaporizes from the electrode.

If an incandescent lamp, the vacuum of which had been thus cleaned up, was allowed to stand unlighted at ordinary temperature, the vacuum, as indicated by the test, would gradually grow poorer, though it would seldom fall to the starting value. If the bulb were heated in an oven at 100 deg. cent. for a few moments, it would also show a poor vacuum again on cooling. If such a spoiled vacuum lamp was again lighted, it would at once commence to recover its previous high vacuum. There was no indication of a fatigue evinced in lamps thus treated.

This explains the fact noticed in the case of most factory made incandescent lamps, that their life at constant voltage varies with the external temperature. It is as though the gas, which is at first present in the space of the sealed bulb and is then thrown upon the walls by the clean-up, is also continually driven off from the walls at a rate dependent upon the wall temperature, and the deposition is bound up with some loss of filament material.

The experiments with the radiometers naturally led to attempts to develop more nearly quantitative apparatus which would still measure the low pressures of gas under consideration in incandescent lamps. Among the promising methods was that described by Pirani (*Ber. Deut. Phys. Ges.* 1906, 686). This was further developed by Dr. Hale of this laboratory, as described in the *Transactions* of the American Electrochemical Society, 1911.

This gage depends on the principal that energy loss from a heated wire in the vacuum to be measured depends on the pressure of the gas present. When the temperature of this wire is low (100 deg. cent., for example), the losses by radiation are relatively small, so that the rate of loss at a constant temperature of wire would serve to determine the gas pressure. Conversely the temperature of this wire, if supplied with constant energy, from the battery, for example, would be higher the lower the gas pressure. This latter scheme was adopted by Dr. Hale, and the gage consisted in a glass bulb sealed directly to the lamp to be measured and containing about two feet of fine platinum wire. This was heated by a current of constant watts and the temperature of the wire was given by knowing its temperature resistance coefficient and measuring the actual resistance for the case in test.

The measurement involved extrapolation towards perfect vacua from comparative measurements made with the new gage and the McLeod gage at pressures high enough so that the latter is reliable. Hale concluded that he could measure differences of pressure of one hundred thousandth of a millimeter of mercury, or a hundredth part the vapor pressure of mercury at zero centigrade. Here was a gage which, unlike the McLeod, exerted no appreciable vapor pressure of its own and therefore could serve to indicate the existing pressure at any period of the life of the lamp. It could disclose the fact if gases were produced within the burning lamp, if the seals or glass leaked at all, and how the clean-up actually changed the vacuum as indicated by the radiometer experiments. In using this gage new and interesting phenomena were disclosed, which must be further studied. In certain cases vacua a little more than perfect are indicated by this gage, and this suggests possible dissociation of the very attenuated gas. Barring this fact, it seems as though the clean-up effect proceeds to as nearly perfect vacuum as we can measure even qualitatively.

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MILITARY TELEGRAPH LINES USING THE POLARIZED SOUNDER AS RECEIVING INSTRUMENT

BY GEORGE R. GUILD

It is well known that, in time of war, the army has considerable difficulty in keeping up its overland telegraph lines, and especially so if these lines are operated on the ordinary Morse system and with wet cells. In actual warfare, in the field, all impedimenta must be reduced to a minimum, and consist of as little perishable material as possible. If, for example, it is desired to operate a closed circuit line of say 300 miles in length about 150 gravity cells would be required, and if the line were to be operated on open circuit it would require about 100 dry cells per station. On the other hand induction telegraphy, so called, allows such a line to be successfully operated with from four to six dry cells per station. This fact and other features of simplicity which it possesses explains the existence of army field induction telegraphy.

Ordinarily the United States Army induction telegraph kit consists of a polarized relay, a four-ohm sounder, key, induction coil, and four dry cells. These instruments are installed in a portable box weighing about 12 pounds. The induction coil is small and the ratio of the winding of its coils is as one is to one hundred, the primary coil consuming about 12 watts at four volts. New sets are being experimented with by the United States Signal Corps with a view of simplifying the present set by replacing the polarized relay and the four-ohm sounder by a polarized sounder, and as the results obtained so far have been very successful it is believed that a new type of kit will soon be adopted somewhat along the lines described in this paper. The writer has conducted a series of tests with induction telegraph circuits with the object in view of obtaining suitable kits and circuits in order that induction telegraphy may be used more extensively in the field than heretofore to displace some, or many, of the closed circuit lines which must be now used.

This paper will describe some of the important phases of single impulse induced current circuits, and at the same time will also indicate the instruments which the writer has found to be best adapted to these circuits. In some cases these instruments may be advantageously used with other than induction circuits, and instances of these circuits are included in this paper.

It has been deemed advisable to first outline briefly the operation of an induction telegraph circuit. For the sake of illustration only, suppose that it is possible to construct an induction coil having an efficiency of 100 per cent. With such a coil as many watts could be obtained from the secondary coil as are expended in the primary. As watts are the product of volts and amperes, and as the voltage of the secondary coil to that applied to the primary coil is in direct ratio to the number of turns in each it will be evident that it is possible to obtain a small current in the secondary circuit at high voltage, sufficient to operate a line, and still do this by drawing only a moderate amperage from the battery in the primary circuit at low voltage.

Of course it is known that current in the secondary circuit exists only while there is an increase or decrease of intensity of current in the primary coil, and further, that the direction in which the current flows in the secondary at the closing of the primary circuit is opposite to that at the opening or breaking of the primary circuit. Consequently, in order to operate a telegraph relay or sounder by a momentary induced or secondary current of reversed polarity it is necessary that the armature of the instrument respond to direction of current flow, and the armature having thus responded it must remain at rest until a current in the opposite direction passes through the instrument and causes the armature to reverse its position. In other words, the relay or sounder must be a polarized instrument.

To overcome resistance of any considerable amount and yet have sufficient current on a line to operate relays, a comparatively high electromotive force is necessary. One way to obtain this electromotive force is to use sufficient cells in series with the line. Another way is to use an induction coil and a few cells with more frequent renewals, drawing a heavy current from these cells at low voltage and increasing the voltage and decreasing the current in the secondary circuit, thus obtaining enough voltage to overcome the considerable resistance of the line and sufficient current to operate polarized relays. For example, the army field kit previously referred to will operate well through a non-inductive resistance of 50,000 ohms with three dry cells, and can even be made to operate, under favorable conditions, through 100,000 ohms.

A type of telegraph sounder employing the well-known principles of the Hughes* relay lends itself so readily to induction telegraph circuits that the writer has used it exclusively in his experiments, either as a sounder, main-line or local, or as a relay. An illustration of this instrument (in this case a relaying sounder) is shown on Plate LI.

Referring to this illustration it will be noticed that the instrument is in appearance very similar to the standard American sounders, except that a permanent horseshoe magnet of considerable strength is bolted at right angles to the lower cores of the electromagnets, one leg of the magnet to each core. The armature is a piece of soft iron. It follows that this use of the horseshoe magnet normally gives a certain polarity to the poles of the electromagnet cores. When a current is passed through the electromagnet coils it will either increase or lessen the strength of this induced magnetic polarity, and will cause the electromagnet cores to attract their armature more strongly if the current through the coils is in such direction as to work in conjunction with the magnetism of the cores due to the horseshoe magnet, or, if the current be in opposite direction, the magnetic effect on the armature may be neutralized, or at least nearly so, allowing the spring to raise the lever.

The sounder is made adjustable so that the lever will remain up until pulled down, and vice versa. This is termed "adjusting the sounder to its neutral position." Or a bias can be given to the lever so that it can be pulled down, but when released will return to the "up" position (and conversely). This latter adjustment enables the sounder to be used as an ordinary main line (or local) instrument.

There appears to be nothing that the ordinary sounder will accomplish that cannot be equally well accomplished with the polarized sounder, while on the other hand the position of the lever of the latter will be reversed by reversals of current flow, which is not the case with the ordinary sounder. This feature makes the polarized sounder desirable for the following reasons.

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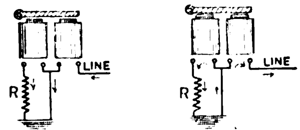
*Maver's "American Telegraphy," p. 240, edition 1912.

Due to the fact that the sounder is polarized and may be differentially wound the instrument can be readily duplexed, responding (Fig. 1) to a current flowing into it from the line, but not responding (Fig. 2) to a current flowing through it from its own station, provided *R* (non-inductive resistance) equals the resistance of the line and that the capacity of the line is also balanced in accordance with the usual arrangement of duplex circuits.

It will respond to a current flowing for an instant in one direction, and its armature will remain attracted (or repelled) until acted upon by an instantaneous current in the opposite direction. Such a current would be produced by the secondary coil of an induction coil when the primary circuit is made or broken.



RESPONDING

NOT RESPONDING

FIGS. 1 AND 2

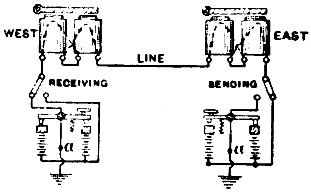


FIG. 3

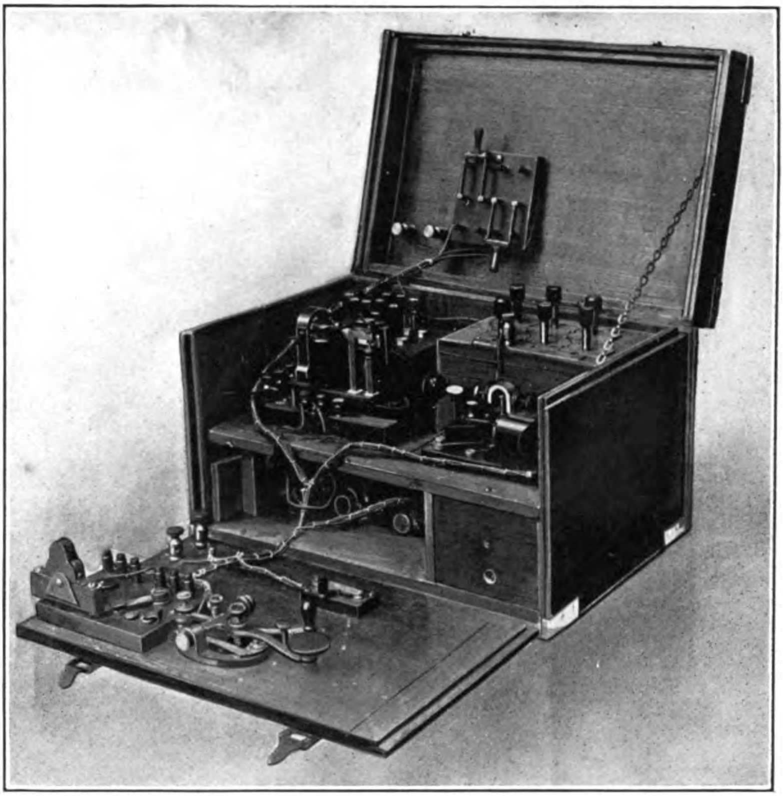
It will operate in the same manner on certain lines in series with a condenser as shown in this paper.

It can be placed directly in the line circuit without a relay or a local battery, and will give firm, readable signals similar to those obtained in a local circuit, with line currents of the ordinary strength used for operating ordinary relays. It gives excellent results on underground lines. As it can be adjusted to operate perfectly through a condenser it is a valuable instrument on lines subject to disturbances by earth currents.

Tests of this sounder seem to show that it is superior in action to an ordinary main-line sounder; that it can be used as a local sounder with good results; that it can be operated equally well on closed or open circuit lines, condenser lines, and induction lines; that used as a polarized relay it is very sensitive.

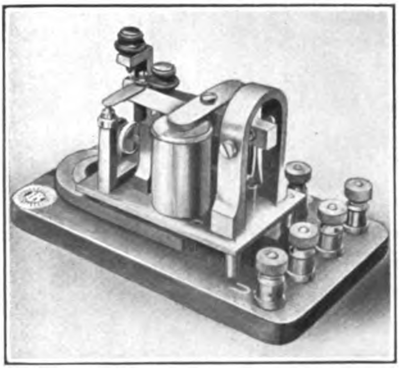
The following are a few circuits with which the sounder can be advantageously used.

Fig. 3 shows the method of connecting the sounders on simplex



[GUILD]

SIMPLEX INDUCTION SET



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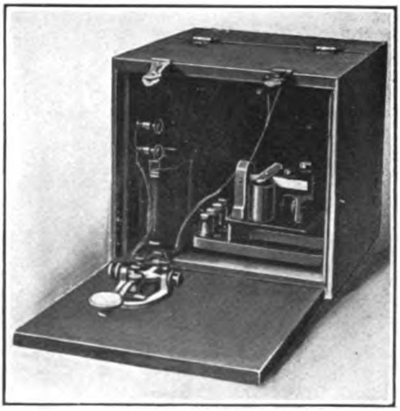
RELAYING SOUNDER



[GUILD]

INDUCTION REPEATER SET

double current split battery open circuit working. The sounders are adjusted to the neutral position, and a double contact key is used. Ten milliamperes are required to operate the instruments. A switch to throw from sending to receiving is shown. Condensers may be placed in series with the line at *a* if desired. In this figure East is sending and West is receiving.

Fig. 4 represents a central battery system; the battery *C B* is located at the central station. The line is taken from the point *O* through a resistance of some two thousand ohms, and the first set is at the central station. Other lines may be connected at *O* as shown, each one of them being first carried through two thousand ohms resistance. Polarized sounders are used at the central and at the way stations, and a two microfarad condenser is in series with each sounder as shown, the sounders, condensers, and keys being bridged between the line and ground.

The action of this current is as follows. When the line is at rest the battery *C B* charges all of the condensers on the line, then when any one station, Station *A* for example, depresses the key a short path to ground is furnished through Station *A* for the discharge of all the other condensers on the line, which actuates their polarized sounders. A path to ground for battery *C B* is likewise furnished through Station *A* when this station depresses its key, hence the necessity for the resistance for about two thousands ohms in order that the battery be not short circuited. The sounder at Station *A* is not effected by the depressing of the key at this station because its condenser is not discharged. When the key at Station *A* is raised all the condensers on the line are again charged, due to the fact that the path to the ground is now interrupted.

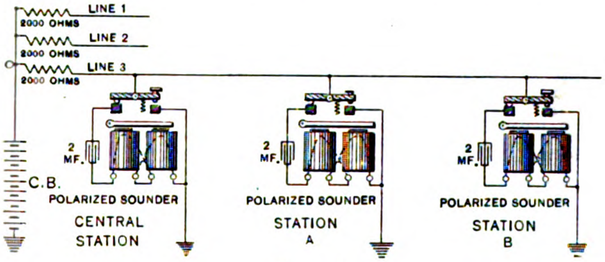


FIG. 4

This circuit operates nicely, an objection to it being, however, that the sender does not hear his own instrument while sending unless another sounder is added.

The use of the sounder with closed or open circuit lines is identical with that of the ordinary sounder. The use of the sounder as a repeating relay for repeater stations is shown later. It is admirably suited to this use, due to the particular manner in which it is made and to its sensitiveness. Most of the circuits due to the writer that appear in this paper are based upon this use of the sounder.

Although the use of this sounder with closed, open, and condenser circuits has been briefly mentioned in preceding pages the real purpose of this paper is to deal with this instrument particularly with reference to its use with induced currents, for it is in the field in time of war that this sounder excels, due to the fact that ideal conditions of line cannot be maintained and that the transportation of means for development of electrical energy is a difficult problem. The ordinary semi-permanent lines and field lines will seldom be over 300 miles in length, and, as will be subsequently shown, the induction field set now in use, or one of improved type, will operate over this distance on three dry cells without difficulty. If greater distance is required, the new sets devised by the writer can be employed as induction repeaters, allowing induction telegraphy to be used over any reasonable length of line on three dry cells per set.

The writer has devised two induction telegraph sets designed to displace the induction telegraph set now used by the Signal Corps. One of these sets is intended for simplex working only, and is composed of the least number of instruments possible for efficient working. The other set is more complicated and is intended as a general repeater and also as an induction telegraph duplex set, both of which sets will now be described.

The simple set consists of one polarized sounder, one key, one induction coil and three dry cells, all suitably and compactly boxed. This set will operate on simplex only, and has a range of about 300 miles on a line strung on poles, and will operate a few miles over a line of bare wire laid on the ground.

Fig. 5 shows the circuits of this set.

B, battery, three dry cells connected in series.
K, closed circuit key with switch removed.
P, primary winding of induction coil 2-ohms resistance.
S, secondary winding of induction coil, 200-ohms resistance.
P S, polarized sounder, 200 ohms per coil.

The ratio of winding of the induction coil is 1 to 100. The illustration on Plate LI shows this simplex induction set.

The action of the polarized sounder (simplex circuit) in either of the induction sets just mentioned is as follows, reference being made to Fig. 6.

This figure represents a battery *B*, key *K*, an induction coil with primary *P* and secondary *S*, and a polarized sounder *P S* adjusted to the neutral position.

When the key *K* is depressed the current will flow through the primary coil in the direction *a* to *b* and will continue to flow until *K* is released. While this current is building up in the primary coil an induced current will flow in the secondary coil from, say, *a′* to *b′* to *d* through polarized sounder coils in series to *e* and back to *a′*, and will continue to flow until the current in the primary coil has reached a maximum, when the current in the secondary will cease, and the secondary coil then becomes, for the time being, totally independent of whether current is or is not flowing in the primary. Hence with the key depressed current may be sent from the distant station through the sounder in the same manner as could be done were the key not depressed. This shows that the key *K* may be either a closed or an open circuit key, and battery *B* may be either wet cells or dry cells, that is, a current may or may not be flowing through the primary coil continuously, and the only effect on the polarized sounder in the two cases is that if the primary circuit is a closed circuit the armature of the sounder will be left at rest on reverse contact to that if the primary circuit is an open circuit. Bearing this in mind it is evident that in all of the induction circuits herein shown the primary circuit may be a closed circuit if desired, care merely being taken to see that the battery is placed to the primary coil with the correct polarity, and no further remark concerning this point need be made. For the sake of uniformity and brevity, however, all induction circuits herein are shown as operated on open primary circuit.

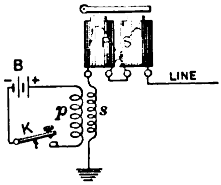


FIG. 5

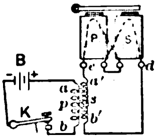


FIG. 6

Now, returning to the action of the sounder; it will be recalled that the key *K* is depressed, that an instantaneous induced current passed through the sounder from a' to b'. This current, though brief as to length of its duration, is sufficient to give enough electromagnetism to the sounder's coils and attract the armature,

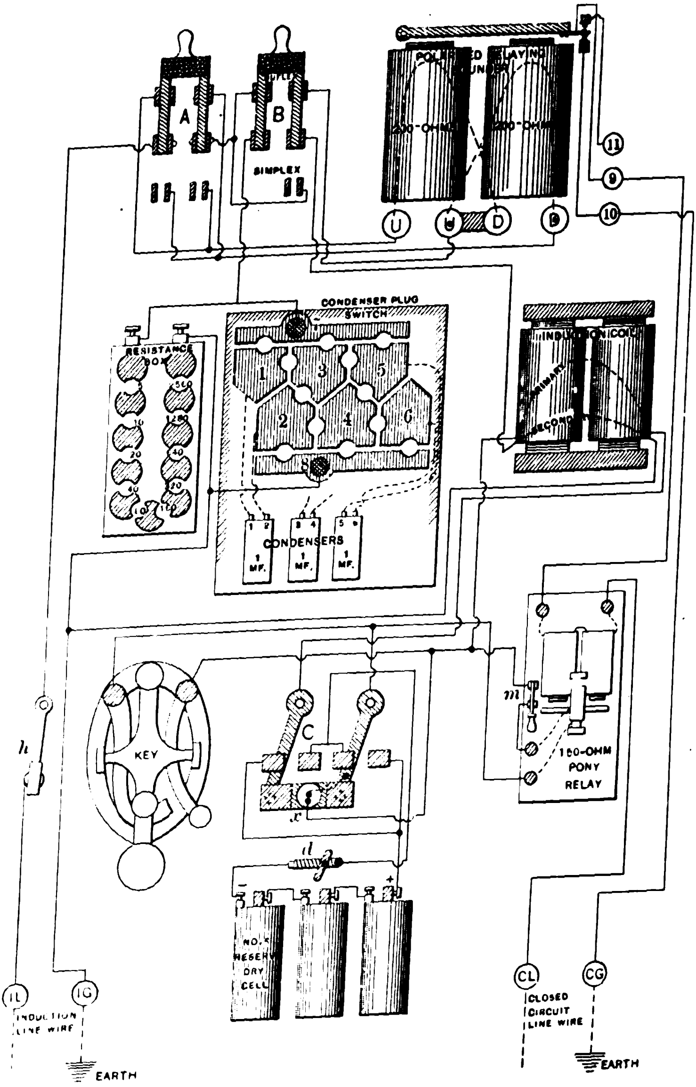


FIG. 7.—FIELD INDUCTION TELEGRAPH REPEATER SET

which is held attracted upon the disappearance of the secondary current by the permanent magnetism of the sounders cores.

Upon releasing the key K the primary current rapidly falls off to zero, and while doing so induces another momentary current in the secondary coil and circuit. This second induced current is now in the opposite direction to that caused by the closing of key *K* and passes through the sounder coils, in an opposite direction to the former induced current. Depending on its direction the electromagnetic effect of this current in the coils of the sounder is either to totally or partially neutralize the effect of the permanent magnetism of the cores, leaving little or no induced magnetism to act upon the armature, and consequently the spring on the lever has time to raise the lever and its armature to " up " position. In the " up " position the armature is too far away from the cores of the coils to be affected much by the prmanent magnetism in them, and hence when the lever is allowed to go up it remains there. Thus by closing and opening the primary circuit by means of the key *K* the armature is made to respond to these actions and the sounder gives the desired reading.

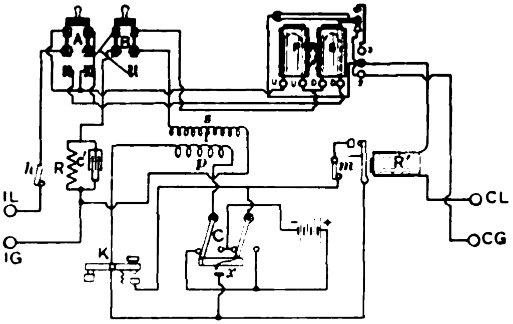


Fig. 8

As the sounder operates on direction of current it will be noticed that placing the battery to primary coils with reversed polarity or reversing the terminals of the secondary coil will have the effect of causing the induced current to pass through and operate the sounder reversely.

In using the sounder as a repeating relay on certain circuits use is made of the fact that current may be passed through each coil separately, the lever being so adjusted that the armature will be held by the current in but one coil.

The illustration on Plate LI shows the induction repeater set.

In discussing the operation of the induction repeater set shown in the illustration reference will be had to Figs. 7 and 8.

Fig. 7 shows the actual wiring and apparatus of this repeater set and Fig. 8 shows the wiring diagrammatically.

PRS, polarized relaying sounder, 200 ohms per coil.

I, induction coil:

p, primary of induction coil.

s, secondary of induction coil.

R, resistance box.

C′, condenser.

R′, 150 ohm pony relay wound with No. 34 enameled wire.

b, battery, consisting of three No. 6 dry cells.

A, double throw double pole switch for reversing the direction of the secondary current through the polarized sounder.

B, double pole double throw switch for throwing from simplex to duplex, as desired.

C, double pole double throw switch for reversing the direction of the primary current through the primary of the induction coil. The handle of the switch has a slight lateral motion on a horizontal axis so that as the switch is being thrown by hand a contact is maintained by this handle in order to keep the primary circuit closed while the switch is being reversed. This action of the switch is necessary only when the set is used as the terminal station of a simplex induction line which is repeating into a closed circuit line. The switch thus serves to leave the distant polarized relaying sounder on proper contact when the induction line is finished working, in order that the closed circuit line be not left open at the repeater station.

IL, binding post for induction line wire.

IG, binding post for induction ground wire.

CL, binding post for closed circuit live wire.

CG, binding post for closed circuit ground wire.

x, contact point on under side of handle of switch *C*.

h, single-pole single-throw switch for opening the line.

m, single-pole single-throw switch for opening the primary circuit of battery *b* to prevent its being closed by relay armature when relay is not in use.

The induction repeater set just referred to is so constructed that it may always be ready for use on the following circuits, by merely throwing certain switches:

As the terminal station of a simplex induction line.

As the terminal station of a duplex induction line.

As the repeater station of a simplex induction line repeating into a simplex closed circuit line, one set used at the repeater station.

As the repeater station of a simplex induction line repeating into an open circuit line, one set used at the repeater station.

As the repeater station of a simplex induction line repeating into another simplex induction line, two sets being used at the repeater station.

By using the instruments of the set and slightly altering the wiring these sets may be used as follows:

As the terminal or intermediate station of a closed circuit line, simplex.

As the repeater station of a simplex closed circuit line repeating into another simplex closed circuit line, two sets used as repeater.

As the repeater station of a simplex closed circuit line repeating into a simplex open circuit line, two sets used as repeater.

As the repeater station of a simplex open circuit line repeating into another simplex open circuit line, two sets used as repeater.

The following is a brief description of the various circuits included in the repeater induction kit to which reference has just been made.

Fig. 9 illustrates the operation of a simplex induction circuit using a polarized sounder.

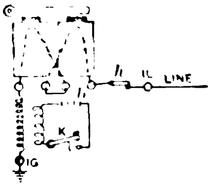


FIG. 9

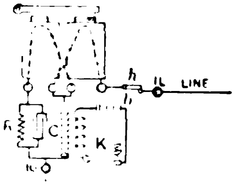


FIG. 10

This figure is the terminal station of a simplex induction line. On depressing the key *K* of this station a secondary current is caused to flow through the polarized sounders of this and the distant station, causing the armatures of these sounders to be actuated. As these sounders have been adjusted to the neutral position the armatures remain attracted at the cessation of the secondary current. On opening the primary circuit by means of the key *K* another secondary current in the opposite direction s caused to flow through both sounders allowing them to release their armatures, which armatures remain released at the cessation of this secondary current. Either station may break by opening the switch *h*.

Fig. 10 illustrates the theory of one terminal station of a duplex induction line, using a polarized sounder.

R and *C* are artificial line resistance and capacity respectively, and the secondary current induced by the closing of the key

K divides equally through the differentially wound coils of the sounder and does not actuate its armature, but the portion of this induced current that goes out on the line does actuate the distant sounder as it does not divide through the coils of that sounder. In the same manner the distant station may operate this station's sounder without interfering with its own, and the line becomes an induction duplex. One feature of this duplex circuit that should commend it is the fact that the resistance and capacity of the artificial line need only approximate that of the line, the instruments will operate perfectly on a considerable discrepancy between the two lines, the real and the artificial. The experiments that the writer has had an opportunity to conduct with this circuit seemed to show that it makes little or no difference whether the resistance of the line is increased or decreased within reasonable limits, limits such as would ordinarily affect the closed circuit duplex quite seriously.

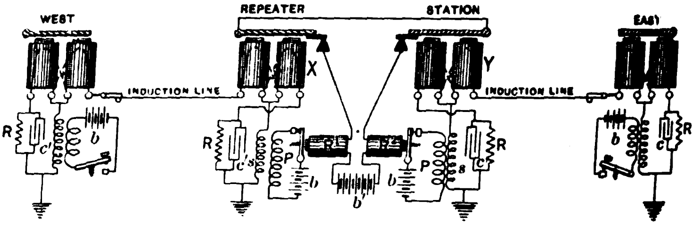


FIG. 11

Figs. 11 and 12 illustrate the theory of an induction to an induction repeater.

The repeater station is composed of two induction repeater sets, *X* and *Y*, battery *b'* being of the closed circuit type. The terminal stations are each composed of one of these repeater sets, with switches thrown to " duplex " but in reality operating as simplex sets. This is accomplished as follows.

West is sending, the make and break of the primary current at West's station induces a secondary current through West's polarized sounder, and this current divides through the coils of this sounder thus not operating it. The portion of the induced current that goes to line passes through the coils of the polarized relaying sounder *X* in multiple and operates *X*, causing the lever of *X* to rise when West's key is depressed. The rising of the lever of *X* opens the circuit of battery *b'* and causes pony relay

R' to release its armature. This causes current to flow through the primary of X's induction coil and sends an induced current through the polarized sounder of X dividedly, not operating this sounder, but the portion that passes to line does operate the distant West sounder. Hence as West sends he hears his own sounder operate with perhaps a very slight drag but not enough to be bothersome.

Returning now to the repeater station. The raising of the lever of X's sounder, as has been stated, breaks the circuit from battery b'. This causes R^2 to release its armature and the operation just described for X occurs with Y and the distant East sounder is operated, the contact of Y being closed all of the time due to the dividing of the current through Y's coils equally. East may break by closing his key. This causes the induced current from East's station to release Y's lever and open the battery of battery b' at Y's contact, and the armatures of both pony relays, R' and R^2 close the circuits for batteries b. These contacts remain closed as long as East's key is closed, and West's sounder becomes and remains silent. Before West can read East he must close the contact on the polarized relaying sounder X. This is done by means of the switch C described under the discussion of Fig. 8.

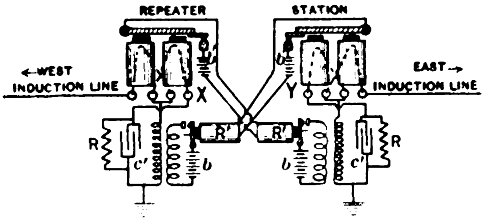


FIG. 12

It is not necessary that the West and East stations be wired as for duplex as shown in Fig. 11, but if open circuit cells are used, as they would be in army field kits, this manner of wiring is necessary. If, however, closed circuit cells are used at these terminal stations the simplex wiring shown in Fig. 9 will suffice, a closed primary circuit being used. Of course the latter would be much the simpler method.

Fig. 12 differs from Fig. 11 only in the manner in which the pony relays of the repeater sets are connected to their closed circuit batteries. Only the wiring of the repeater station is here given, the wiring of the terminal West and East stations being the same as those given in Fig. 11.

Fig. 12 operates in much the same manner as just described for Fig. 11 except that when West is sending, his own sounder remains silent and operates when East breaks, for in this case West's sounder can be operated only by the contact of Y being opened and closed. East may break in either of these two methods of wiring by merely opening his line switch. This destroys the balance of the line for the *Y* set of the repeater station, and in the first case West fails to hear his own sounder when he should hear it if East had not broken, and in the second case the opposite obtains.

The choice of these two circuits depends on what is desired. For instance, Fig. 11 is the better circuit if the terminal stations are to be wired for duplex operation (using dry batteries) and if there is only one repeater station on the line. Fig. 12 must be used if there is more than one repeater station on the line.

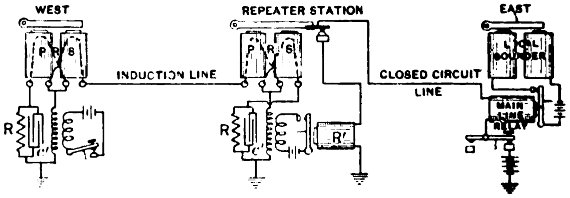


FIG. 13

Fig. 13 illustrates the theory of an induction to closed circuit repeater.

As described for Fig. 11 the polarized relaying sounder of the repeating set does not operate when East is sending. When West closes his key he causes the polarized relaying sounder of the repeater station to operate, thus breaking and closing East's closed circuit line at the contact point on the polarized relaying sounder of the repeater set. This has exactly the same effect on West's sounder as described for the operation of Fig. 11, and West hears his sounder as long as East does not break. When East sends to West the former opens his closed circuit line at his key and consequently allows the pony relay *R′* of the repeater station to release its armature and send an induced current over the line to operate West's sounder, at the same time not interfering with the position of the lever of the polarized relaying sounder of the repeater station. West may break East by depressing his key or by opening the line. West must leave the lever of the polarized relaying sounder of the repeater station on *down* contact when through working. This is accomplished by means of the switch *C* previously referred to. As in Fig. 11, it is the "back kick" of the repeater station that operates West's sounder.

The arrangement of circuits and apparatus shown in Fig. 13 are operative on a line where there is only one repeater station on the line, but where a closed circuit line repeats into an induction line and this line in turn repeats into another induction line the wiring given in Fig. 13 will not operate, and the repeater station must be wired in accordance with the arrangement shown in Fig. 14.

Fig. 14 illustrates the theory of an induction to closed circuit repeater, the repeater station only being given. The terminal stations are shown in Fig. 13. It will be noticed that a 150-ohm pony relay is employed in this circuit as in the others, but that it is shunted with 40 ohms resistance. This is done merely to retain the instruments composing the induction repeater set. This relay might be a 20-ohm relay and in this case it would not be shunted, and the battery *b* might be reduced in voltage.

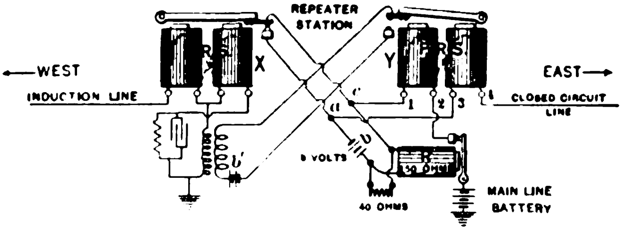


FIG. 14

This circuit, Fig. 14, is composed of the induction wiring for duplex for the left half of the repeater set, while the right half utilizes the individual coils of the polarized sounder separately. The battery *b′* may be either of the closed or open circuit type. In this circuit it is supposed to be the latter, consequently the armature of *Y* is given a natural bias that will cause it to normally remain on down contact but the presence of a current in either one of its coils will allow the spring to draw it upward.

If battery *b′* were a closed circuit battery the armature of *Y* would be adjusted reversely. The operation of this repeater requires that *X* shall remain unaffected while East is sending and that *Y* shall remain unaffected while West is sending. The method whereby the former is accomplished has been discussed in former repeaters, and it remains to show only how *Y* remains silent when West sends. The closed circuit line is brought into *Y* at post 4 and passes through one coil of the polarized relaying sounder, leaving that coil at post 2 and passing to ground through the armature of the pony relay *R′*. As long as the armature of *X* is closed battery *b* discharges current through the pony relay *R′*, and holds the armature of this relay closed, and as the circuit from " *a* " through the contact points of *X* to *c* is practically short circuited no appreciable current will flow through the left coil of *Y* as long as contact at *X* remains closed; hence the armature of *Y* will be affected by the presence or absence of current in the right coil of *Y* only.

As East opens the closed circuit line he removes current from this right coil, and the armature of *Y* being no longer drawn up by current in *Y* as stated this armature goes to down position and closes the circuit of *b′* and causes an induced current to flow over the West induction line and throws West's sounder to up contact. Therefore as East closes and opens his key he causes West's sounder to respond. On the other hand when West sends he causes the left polarized relaying sounder *X* to operate and when *X* releases its armature it removes the low resistance shunt from around the left coil of the polarized relaying sounder *Y* and battery *b* now discharges current into this left coil which keeps the armature of *Y* up. At the same time the armature of the pony relay *R′* is released, due to the fact that its spring is so adjusted that when the contract of *X* is closed the battery *b* gives *R′* sufficient current to attract its armature, but when the contact of *X* is open and the resistance of the 200-ohm coil of *Y* is added to that of *R′* the current from battery *b* is not sufficient to hold the armature of *R′*. The opening of *R′* opens the closed circuit line at this point and consequently operates East's sounder accordingly. It will be evident that care must be exercised to see that the main line battery of the closed circuit line and the local battery *b* are connected to *Y* with the correct polarity to cause *Y*'s armature to properly respond to current in either of the coils of *Y*. The spring of *R′* must be so adjusted that the armature of *R′* will remain closed on the strong current but will be released on the weak current passing through the relay R'. This is amply sufficient to eliminate the necessity for a fine adjustment of relay R'.

Fig. 15 illustrates the theory of the induction to open circuit repeater.

As this circuit differs very little from the theory of the induction to closed circuit repeater given in Fig. 13 it is not considered necessary to discuss its operation.

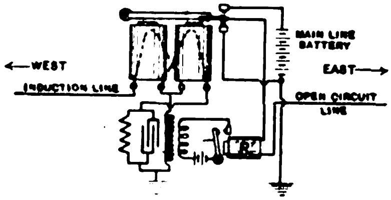


FIG. 15

Fig. 16 illustrates the theory of the open circuit to open circuit repeater.

This is the theory of an open circuit to open circuit repeater given in Maver's "American Telegraphy," except that polarized relaying sounders are used in place of ordinary relays. When West puts battery to line he causes the right pony relay R^2 to close its armature. This closes the local battery circuit of b' and closes the armature of Y which in turn puts battery to the East line and operates East's sounder. East may break only by operating his key and interfering with West's sending.

Fig. 17 illustrates the theory of the closed circuit to open circuit repeater that depends for its action on the employment of a polarized relaying sounder.

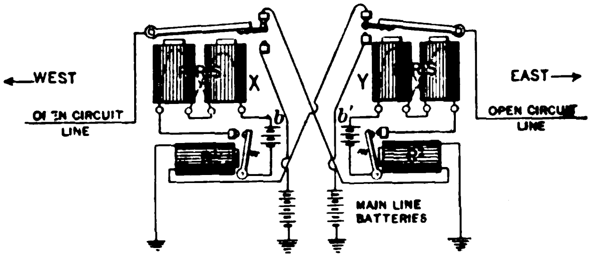


FIG. 16

The instruments composing this repeater are one polarized relaying sounder, one 150-ohm relay and one 20-ohm relay.

The closed circuit main line battery $C\ B$ normally holds the armature of the polarized relaying sounder on down contact. The breaking of this circuit throws this armature to up contact (by means of the upward bias previously given to the lever) and puts the open circuit main line battery *O B* to the open circuit line unless the contact of relay R^2 has been broken, as would be the case if West were sending to East, for then the short circuit (the armature of R^2) has been removed from the local battery *b* and this battery now furnishes current to the polarized relaying sounder as well as to R' and holds the polarized relaying sounder's armature down but releases the armature of R^1, due to the fact that R^1 will hold its armature only when battery *L B* has been short circuited by means of the armature of R^2; the releasing of armature R' opens East's line. It must be remembered that the West line normally has no current in it, hence the armature of R^2 is normally on released contact as shown. The only way East may break West is to interfere with West's sending, but West may break East in the ordinary manner. This repeater may be quite coarsely adjusted and yet give excellent results.

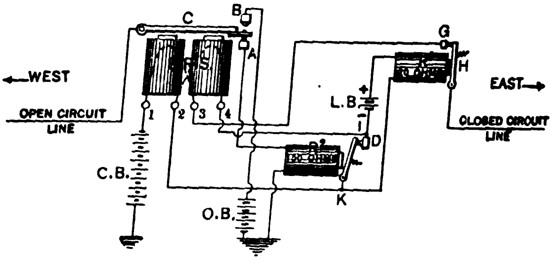


FIG. 17

Fig. 18 illustrates the theory of the closed circuit to closed circuit repeater using polarized relaying sounders.

It will be noticed that two 150-ohm relays shunted with 40 ohms resistance are used. This is only to allow the instruments in the writer's induction repeater set to be employed, in practice it would be better to employ two 20-ohm relays in place of the 150-ohm instruments.

It will also be noticed that the armature of *X* is a shunt to relay *Y* and likewise the armature of *X'* is a shunt to *Y'*. This repeater operates on the principle described for the one-half of Fig. 14 and it is therefore not deemed necessary to more fully describe its action. However, as the setting up of this repeater is apt to give trouble to one not familiar with its operation, the method of doing so is here given.

Adjust the armatures of *X* and *X'* so that they will normally remain on up contact, or stop, when no current is in either coil, but will be readily attracted by a current of from 20 to 40 milliamperes flowing in one coil. Bring West line to post 1, connect post 3 with *b′*, *g′*, and battery *h′*, to ground. This should cause the armature of *X* to be attracted or released as contact is made or broken at *b*, if *X* acts reversely transfer wires at posts 3 and 1 or change the polarity of the main line battery *h′*.

Do the same with *X′* if necessary. Assuming the proper connections to be as in figure, temporarily disconnect West and East lines from posts 1 and 4 respectively. Wire in relay *Y* as follows: Relay to *d*, to *a*, to *f*, *c* to 1, and to relay. If a 150-ohm relay is used shunt with 40 ohms as shown. Now close and open armature *X* contact at *f* and adjust relay *Y* armature so that it will just respond to the closing and opening of *f*. Do the same with relay *Y′*. Now see that contacts at *f* and *f′* are broken and kept broken temporarily and wire *a* to 3′. This connection should cause armature of *X′* to close and remain closed but should not close relay *Y* armature. If *X′* armature is repelled instead of attracted reverse the polarity of battery *d*. Close and open armature of *X*. This should cause the armature of *X′* to open and close, and the armature of *Y* to close and open. Now disconnect wire at 3′ for a moment and see that armature of *X′* is up. Wire *a′* to 2. This should attract armature of *X* but not that of relay *Y′*. If it repels, reverse the polarity of battery *d′*. Now close and open the armature of *X′*. This should open and close the armature of *X*, and close and open the armature of relay *Y′*. Now connect all disconnected wires (at 1, 4′, and 3′) and repeater should operate.

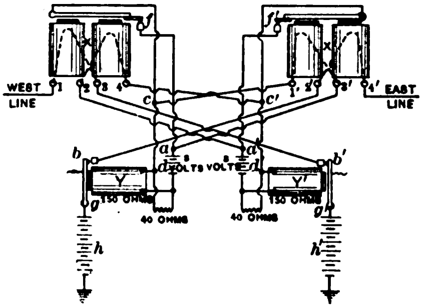


FIG. 18

The writer advocates the use of the polarized sounder exclusively on all Army Signal Corps land lines in time of war, and believes that this sounder has widened the possible scope of induction telegraph circuits for the more advanced lines in the presence of the enemy, the closed circuit system being used on only such lines as may be considered permanent lines. Consequently the writer has endeavored to produce a telegraph field set that will meet every possible telegraphic condition likely to be encountered by troops in the field. This set must be compact in size, contain few instruments, simple in operative principle and easy and ready of adjustment.

It follows that such a set must combine the closed circuit and induction telegraph features. It must, either alone or in conjunction with a duplicate set, be able to repeat from any one kind of a simplex line into another kind, in order that a partially destroyed line can be hastily " patched " or extended. It is not necessary, however, that such a set be used on duplex or quadruplex, as such lines cannot, as field lines, be well maintained in time of war. On the other hand, an induction telegraph line of this type may be easily duplexed, consequently it would be advantageous to have such a set capable of being used as a terminal station of a duplex induction line.

Hence it will be seen from the foregoing that the set fulfills practically all the requirements of a station set for virtually any kind of a military telegraph line that might be employed by armies in time of war.

In order to accomplish these results the writer determined upon the necessary instruments to use with such a set, then he adapted well known circuits to these instruments wherever this was possible, and where not possible he either altered these circuits to fit the instruments used, or devised new circuits to accomplish the desired results.

Acknowledgment is therefore due the British Insulated and Helsby Cable Company for the circuits shown in Figs. 3 and 4. To Mr. William Maver, Jr. in his " American Telegraphy " for the circuits shown in Fig. 16 which has been slightly altered by the writer and to Major Edgar Russel, U. S. Signal Corps for valuable assistance given the writer in some of his experiments with these circuits. The other circuits in this paper are believed to be original circuits. Of course no originality is claimed for the principle of operation of an induction telegraph circuit.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 28, 1912.

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MOTOR STARTING CURRENTS AS AFFECTING LARGE TRANSMISSION SYSTEMS

BY P. M. LINCOLN

From time to time those responsible for the operation of electrical systems have displayed a disposition to place a definite limit upon the size of motors which they will allow upon their circuits. This tendency seems to be more pronounced in alternating-current than in direct-current systems, but is observable in both. Moreover, in alternating-current systems the tendency is not confined to central stations for city supply, but is spreading to the larger transmission systems that deal in wholesale power.

So far as the writer has been able to analyze, the reasoning that has led to these restrictions is about as follows:

1. A desire to avoid tying up too much load to a single piece of apparatus, thereby endangering a comparatively large income by the loss of a single motor.
2. A fear that the starting currents and the fluctuations in the operating currents of relatively large motors will cause fluctuations in voltage.
3. A fear, more or less undefined, that the cumulative effect of starting many large motors at nearly the same hour will cause so large a draft of current as to be beyond the ability of the generating plant to take care of it.

It may be of interest to analyze further these reasons and see just how much bearing they may have upon a typical large transmission system which presumably deals in wholesale power only.

The writer recognizes the first of the above reasons as an entirely legitimate one. It is, no doubt, desirable to keep the power supply as much sub-divided as possible, thereby avoiding the danger of a relatively large loss of revenue by crippling of a single motor. Its application, however, is wholly commercial in its nature. There are many cases where these same commercial considerations may make it desirable to advocate rather than deprecate the use of large motors, since on no other basis can some kinds of business be secured. Take for example an existing cotton mill or other industry that is already equipped with an engine connected to its load by shafting and belts. The most natural way of applying electric drive to such a case is simply to substitute one large motor in place of the engine. Commercial consideration will often demand that a given load be taken in this manner or not at all. This case is cited merely to indicate that commercial considerations are not, and of necessity cannot be, controlling in fixing the size of motors or in any ruling which looks toward the limitation of the size of motors which might be permitted on a given system. The size of the motor is simply a matter of expediency. If the advantages of sub-division can be obtained along with electric drive well and good, but if circumstances forbid these advantages, also well and good. The decision as dictated by commercial considerations will be to take the business however it can be obtained, entirely independent of the size of the motor that may thereby be placed on the system.

The second reason mentioned above, namely, the desire of avoiding voltage fluctuations, is also one that must be recognized as having a logical basis. However, this reason is one which appeals with much more force to the typical city supply system, whose main function is the supply of lighting, than to the large transmission system for the supply of wholesale power. In any event the logic of any ruling having this object in view demands not simply a limitation in the size of the motor but a consideration as well of other conditions that surround the installation of this motor. The point involved is simply the question of the voltage fluctuation which will be caused when a given motor is started or stopped or when its load fluctuates. The voltage fluctuation depends not only upon the size of the motor but also among other things upon the size and regulation of the transformers supplying the motor and upon the size, voltage and length of the transmission line connecting it with the source of power. A logical restriction which has for its object, the elimination of voltage fluctuation, should depend even more upon these other features than upon the size of the motor. A five-h.p. motor, for instance, supplied along with some lighting customers, by a three-kw. transformer at the end of a comparatively long and low-voltage transmission might be more of a menace to lighting in its neighborhood than a 100-h.p. motor close to the power station and supplied by large capacity, high voltage transmission lines and good regulating transformers.

Any restriction which has as its basis the elimination of voltage fluctuation is, as indicated above, much more applicable to a central city supply station than to a large transmission system dealing in wholesale power. It is highly important for the city supply station to maintain voltage as steady as possible, since a large part of its revenue is derived from the supply of lights. With the transmission system supplying wholesale power, however, the conditions are far different, the revenue from lighting being a very small proportion of its total revenue. The responsibility for voltage fluctuations at customer's premises is, therefore, by no means as heavy as it is with the city supply system.

In general there are two effects that must be borne in mind when considering the question of voltage fluctuations that may be caused by the presence of motors, and these two considerations hold whether the primary object of the circuit in question is the supply of lighting or the supply of wholesale power. These two effects are; first, the transient fluctuation of voltage due to starting current or to a change in running current, and second, the permanent voltage which is due to the permanent assumption or rejection of load by these motors. In dealing with the wholesale supply lines much of the first mentioned variety of voltage fluctuation may be forgiven since it is confined to a few relatively short and predetermined periods of the day, namely, the regular morning, noon and evening starting and quitting hours of the mills and factories that are supplied with power. This is particularly true since the customers who make use of wholesale power supplies directly for lighting, invariably recognize that they are applying it to a use not primarily intended and are willing to make allowances therefore. It is sometimes necessary to take some special means to care for the permanent voltage change where the power circuits are used directly for lighting, since the difference in voltage between loaded and unloaded line may reach such a value as to be destructive to the lamps. However, where the typical individual mill draws a starting current from the line that is less than the running current (as will be shown later in this discussion), it is evident that the question of motor starting current and transient voltage fluctuation caused thereby is of secondary importance.

The third cause for contemplating the limitation of the size of motors mentioned in the opening paragraph, namely, the fear that the draft of starting current of many motors starting about the same time may be beyond the capacity of the power plant, is the question whose investigation has led to the preparation of this paper. The conditions which led up to this investigation are, briefly, as follows:

A certain large transmission system operating in the south at one time in the course of its growth experienced considerable difficulty in picking up its load at the time of the usual morning start of the mills. In this case, as is usual with southern transmission systems, the most of the load consisted of cotton mills, which started up nearly the same hour of the morning all over the system. From certain effects noted it seemed that the starting currents taken by the motors at these periods were the cause of the failure to pick up the load and it was largely this consideration that led this particular system to consider a restriction in the size of the motors which might be allowed upon its circuits. This attitude led in turn to taking up for systematic investigation the general question of starting conditions which might actually be found in the mills that were taking power from this company's lines. An investigation of this character was, therefore, undertaken.

The method of making this investigation was extremely simple. Graphic recording meters were placed in the supply circuits of the mill under test. Meters showing the draft of both current and kilowatts were used in each case so that both the kilovolt-amperes and the kilowatts of the mill could be secured. The effect during starting periods of the mill could thereby be readily observed and record thereof made. Nine typical mills were selected and tests of this character made upon each of them. A number of starts, both morning and noon, were made, in order to avoid the possibility of observing some condition which was not entirely typical.

A summary of the results which were obtained upon these nine mills by these tests are contained in the following table.

In addition to this summary, some of the more representative records made by the graphic meters are reproduced herewith.

Mill No.	Number of motors	Total capacity of motors in h.p.	Type of motors	Capacity of largest motor in h.p.	Percentage of total capacity in largest motors	Excess of demand in starting period over running period	
						In kv-a.	In kw.
1	37	981	Wound Secondary	100	10.2	None	None
2	257	2440	Wound Secondary	125	5.0	None	None
3	31	1284	Squirrel Cage	150	11.7	None	None
4	37	3055	Squirrel Cage	150	4.9	None	None
5	24	457	Squirrel Cage	35	7.7	None	None
6	24	2626	Wound Secondary	175	6.7	None	None
7	2	150	Squirrel Cage	75	50.0	25%	25%
8	12	1125	Wound Secondary	175	15.5	None	None
9	3	300	Squirrel Cage	200	66.7	50%	None

It was recognized that in obtaining records of the starting conditions there was a possibility of error owing to the time lag of the graphic meters behind the actual current and kilowatt conditions which produced the meter indications. This matter was given careful attention in the taking of these particular records. The speed of the pen was adjustable in the graphic meters used and this speed was so fixed that on the one hand the pen did not move so fast as to overshoot the amperes per kilowatt it was endeavoring to follow and on the other hand it had sufficient speed so as not to have too great a discrepancy between actual amperes or kilowatts and the position of the pen at the same time. The range of adjustment was such as to allow a a speed of pen which would travel over the entire range in less than five seconds. Since the process of starting a large motor is one which always requires a period several times as long as this and further since the travel of the pen is never but a fraction of the entire scale, we may rest assured that the graphic meter indications which are shown here give a reasonably accurate indication of the starting conditions which we are observing.

Figs 1 A and 1 B show for instance the starting conditions in a cotton mill, equipped with total of 1284 h.p. in motors. This is the mill given as No. 3 in the foregoing summary. In this mill there are two motors of 150-h.p. each and three of 100-

h.p. each. All motors in this particular mill are of the squirrel cage type. An inspection of the records reproduced in Figs. 1 A and 1 B shows at once that the maximum demand during

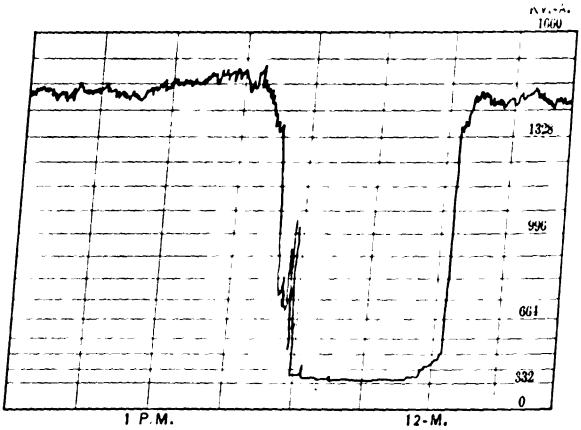

FIG. 1A.

the starting period as compared to the demand during the running period is less than 70 per cent in kilovolt-amperes and about 50 per cent in kilowatts.

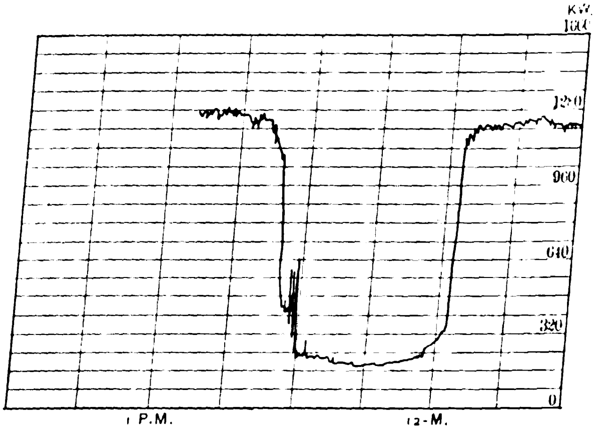

FIG. 1B.

Figs. 2 A and 2 B show the conditions in another mill, No. 8 in the summary. Here the maximum demand during starting period is about 70 per cent of the running kilovolt-amperes and about 62 per cent of the running kilowatts. The motors in this case are of the wound rotor type instead of squirrel cage as in the preceding case. The result of this difference in type of motor is shown in the fact that the kilovolt-amperes and kilowatts during the starting period come nearer together than is the case with the squirrel cage motor. On the other hand a comparison of the charts indicates that the kilowatt of the wound rotor motor taken during the starting period are higher than for the squirrel cage type. It is, of course, possible to obtain much more rapid acceleration with the wound rotor type than with the squirrel cage type, and this power placed in the hands of a mill operator who is in a hurry to get started in the morning may lead to drafts of current during the starting period that are considerably greater with the wound rotor type than with the squirrel cage type. This is a fact which does not seem to have been properly appreciated by those who are using motors for mill purposes.

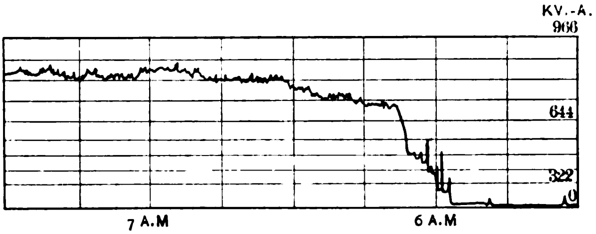

FIG. 2A

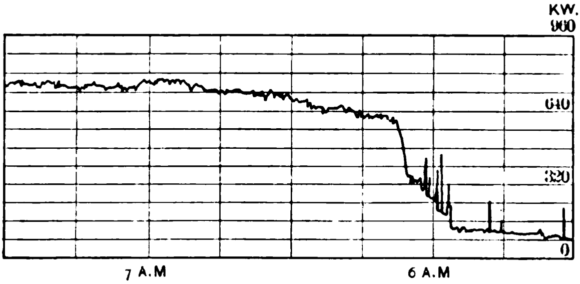

FIG. 2B

Figs. 3 A and 3 B illustrate mill No. 6 in the foregoing summary. The capacity of the largest motor in this mill is the same as in No. 8 just described, but the total capacity of all motors is more than double that in mill No. 8. Although the actual kilovolt-amperes and kilowatts taken for starting a single motor are about the same they become a smaller proportion of the running conditions.

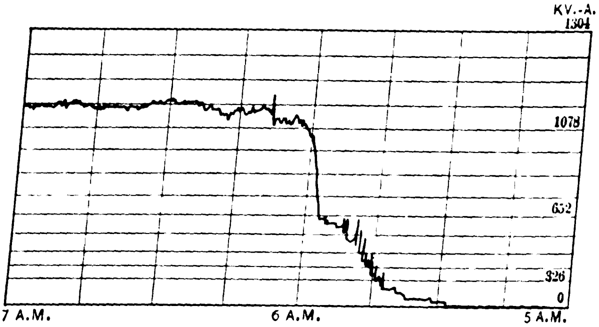

FIG. 3A

Figs. 4 A and 4 B show by far the most severe condition of any that was found in these tests. This mill is No. 9 in the summary, and is provided with only two motors, one a 200-h.p. and the other 100-h.p., both of the squirrel cage type. In this case, therefore, the largest motor amounts to two-thirds the total motor capacity. However, even in this most severe case the kilovolt-amperes during the starting period exceed the running kilovolt-ampere by only 50 per cent and the kilowatts during the starting period does not exceed the running kilowatts at all. If this mill had had a total of 500 h.p. instead of only 300 h.p., the starting kilovolt-amperes would not have exceeded

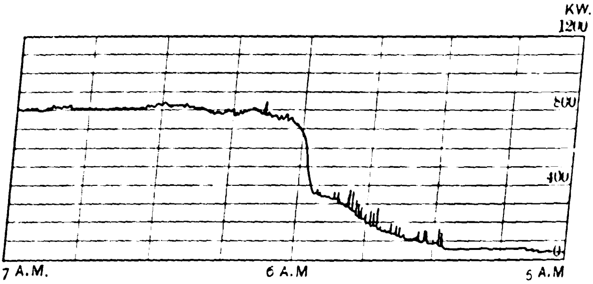

FIG. 3B

the running kilovolt-amperes. We might note if this mill had been increased to a total of 500 h.p., its total capacity would have been only about 20 per cent of mill No. 4 and only about 25 per cent of mills No. 2 and No. 6. The foregoing records are typical of those for all of the other mills taken. On account of this similarity no further records are here reproduced. There are some conclusions which may readily be drawn from an inspection of these records and the foregoing summary of the nine mills that were observed.

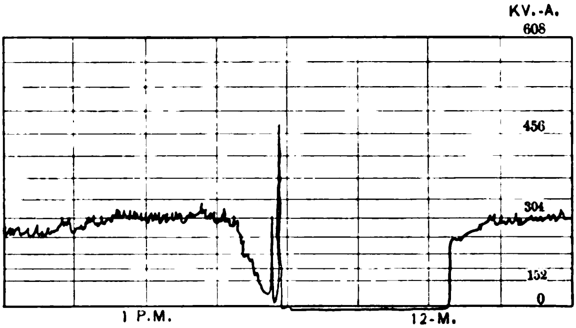

FIG. 4A

In the first place it is evident that so long as the largest motor in a mill is less than a certain percentage of the total capacity in motors, the power demanded for starting purposes will always be less than for running purposes and this will be true no matter whether the demand be measured in kilovolt-amperes or in kilowatts. The evidence of the foregoing records indicates that the largest motor may be at least 25 per cent of the total capacity

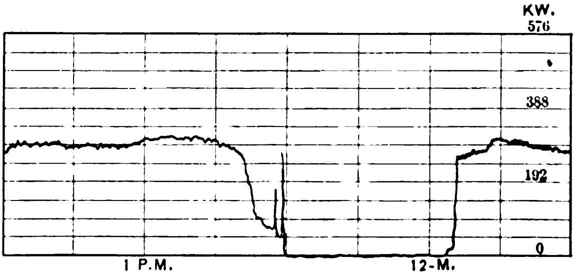

FIG. 4B

in a given mill and still this relation will hold. Possibly the largest motor may be even higher than this percentage of the total, but 25 per cent is certainly a safe figure, judging by the actual records taken.

It is further evident that so long as the current during the starting period is less than during the running period the draft of starting current cannot be a menace so far as ability to pick up load is concerned. A power plant that can pick up and carry the running current can also pick up and carry the starting current, provided this starting current is less than the running current. What is true of one mill is, of course, still more true when many of these mills are carried upon a given transmission system. The foregoing summary shows three mills that have total capacity of more than 2000 h.p., one of them exceeding 3000 h.p. Twenty-five per cent of the total capacity of any one of these mills will mean a single motor having a capacity of 500 to 750 h.p. Therefore, in any one of these mills a motor of 500 h.p. could have been started and still the draft of current during running conditions would have been more than that during starting conditions. If the starting of a 500-h.p. motor can be accomplished in one mill without exceeding a safe limit, there is no reason why the same thing cannot be done in another independent of the total capacity. In other words, so far as picking up the load is concerned, this particular system can certainly take care of single motors as large at least as 500 h.p.

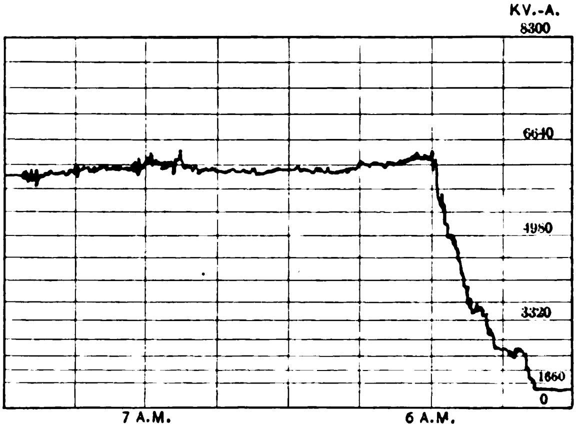

FIG. 5

The writer does not mean to say that he advocates motors of so large a size as this, since he believes that they are objectionable for other reasons, but so far as the ability to pick up the load is concerned there seems to be no doubt that motors of this size are entirely feasible. In fact, if necessary, the writer sees no reason why from this standpoint the size of the maximum motor cannot be increased considerably if such a step were ever found necessary.

While the foregoing records were being taken on individual mills there were also similar instruments recording the output of one of the high-tension lines feeding this system. Fig. 5 is a typical record of one of these transmission lines at the power plant. This record was taken during a typical morning start. The shape and character of this record does not indicate any possibility of distress on account of current draft during starting period.

A further consideration of these graphic records indicates almost to a certainty that it was not the motor starting currents the failure to pick up load, but the high rate at which increments of real kilowatt-load are assumed by the power during the starting period. The source of power in this case was water power, and it is well known that water-power plants are by nature much more sluggish in their ability to assume increments of real load than are steam plants. It seems very probable, therefore, that the cause of the inability to pick up load was due to the high rate of real kilowatt assumption coupled probably with an unusually sluggish adjustment of governors.

This probability seems all the more certain when we consider the method of starting up cotton mills. The method used in such mills is first to start all motors some five or 10 minutes before the blowing of the morning or noon whistle. However, the starting of the motors does not put into operation the looms and other mill machinery that these motors drive. Each motor drives a more or less extensive system of countershafting to which the individual looms and other machinery are connected by tight and loose pulleys. Therefore, until the starting whistle blows, each motor operates only a relatively short section of countershafting. As soon as the starting whistle blows, each operator starts his own group of machines as rapidly as possible and it is during this period that the real kilowatt load rises so rapidly. An inspection of the accompanying graphic records clearly indicates the period at which the real load is thrown on.

From the data that have been given herein, the writer believes that the following conclusion is entirely logical.

That the only logical restriction in size of motor is one that will prevent it becoming more than 25 per cent of the capacity of the largest mill on the system. Such a restriction as this usually leads to so large a motor that no restriction whatever is necessary.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 28, 1912.

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OPERATING CHARACTERISTICS OF LARGE TURBO-GENERATORS

BY A. B. FIELD

The requirements of the station engineer, with regard to the operating characteristics of large alternators, have materially changed during the last few years, concurrently with the rapid increase of size, measured in kw., of the individual power houses and of the individual generating units. Some characteristics which ten years ago were striven for, are now avoided and considered actually detrimental.

It is proposed here to consider briefly, the trend of modern practice in respect of some of these requirements.

The condition referred to, is not merely the result of increasing size of units, and of groups of units, but has been effected for instance, by the radical change in speed for a given output, by changed methods of operation, etc. It was not many years ago that the largest rating of turbo generators offered for a speed of 3600 rev. per min., was 500 kw., and even that was apt to be a troublesome machine on account of a design ill adapted to the speed.

At the present time there are thoroughly satisfactory generators in operation in this country having a continuous rating of 5000 kv-a. at 3600 rev. per min., and in Europe 4000 kv-a. at 3000 rev. per min. Eight years ago 750 rev. per min. was a high speed for 7500 kw., four-pole generators. At the present date six-pole turbo alternators of over 20,000 kw. at 1000 rev. per min. in a single unit, have been constructed in Europe; and in this country two-pole generators for the same output at 50 per cent higher speed are under construction, and four-pole machines for 19,000 kv-a. output at 87 per cent higher speed, or 1875 rev. per min. From an electrical point of view, these high speeds are not economically desirable for these ratings, but the advantages to be gained when considering the set as a whole—turbine and generator—warrant their adoption, particularly as they entail no smaller factors of safety than have been tolerated in the smaller machines in the past. The size of the unit has been continually pushed further, and if there should be a sufficient call from the steam turbine builder and the operator, for a speed of 1500 rev. per min. for still larger sets there is little doubt but that 30,000 or 35,000 kv-a. units for high power factor operation may later be built of the two-pole type, though possibly we may then no longer depend for cooling upon the methods at present in use.

In a recent paper before this Institute, Mr. Samuel Insull advocated the concentration of power generation for public services in each district, and pointed out that in Greater New York there was already a total developed load of 600,000 to 700,000 kw. Without discussing Mr. Insull's arguments, we may note that the company of which he is the president committed itself more than a year ago to a 240,000-kw. station in Chicago, in addition to its two large stations at Fisk and Quarry Streets. Again should the near future see any developments in Europe along the directions hinted at recently by Sir William Ramsay, with regard to the production of power from coal at the pit mouth, and turbine units be used, the size of these units would necessarily be much larger than any hitherto constructed. In fact, we must recognize that we have not yet reached the era of the " large " generator, though we cannot say, with quite the same assurance, that the high speed, relatively to output, at present in evidence is to be similarly progressive.

In the early days of alternating current station practice, alternators were sometimes specified " to be capable of running five minutes on a dead short circuit with normal excitation without injury," and when close regulation was not also called for, this clause was generally agreed to by the manufacturers. Comparatively little attention was paid to the way in which the short circuit was introduced, and such a requirement would have been considered to be met by short circuiting the generator and then bringing up the excitation to normal value; in fact in the case of the type of generator involved, viz.: slow speed, small rating, with many poles, the instantaneous current on short circuiting would not be many times the sustained short circuit current.

Conditions are very different, however, with the machines built now, and operating engineers are frequently wisely specifying that the machines they buy are to be capable of being short circuited suddenly, when running at full speed fully excited, without any mechanical or electrical injury resulting. They are aware that under such conditions the current flowing through the stator winding may be very many times the final steady value obtaining a minute or two after short circuiting. This requirement is by no means an easy one to meet sometimes, and necessitates details of construction which are somewhat costly and have some other disadvantages as well. However, it is recognized by some of the manufacturing companies that the operator has a good case, and that even if, in an up to date station, the arrangements should be such that an involuntary test of this nature is rare, yet the ability of the generator to stand such a test is a good guarantee that the machine will meet a number of other conditions occurring in practice which cannot be covered in detail in a purchasing specification.

The amount of instantaneous short circuit current is of interest to the operating engineer from two points of view; viz. the effect upon his generator and that upon his circuit opening devices. Both aspects have been simultaneously studied carefully by the manufacturers, so that now, while the current to be dealt with has been kept within moderate limits, and generator constructions have been developed which are amply able to stand the strains, at the same time switch gear is available which will meet the needs at present in sight.

It is of interest to consider the features which influence the amount of the instantaneous short circuit current, the way in which this depends upon size, speed, frequency and regulation, and to do so we must picture in a general way the process by which it is produced. These have been well recognized for some years, but to facilitate the argument they are briefly described below.

Consider a generator running on no-load at normal voltage, on which a short circuit is developed between two terminals *B C* at the instant when the voltage *B C* is zero. At this moment, the windings of the short circuited phase are inclosing their maximum rotor flux. If this flux were to be abstracted by the motion of the rotor and no self-inductive or other flux substituted, the current would mount up to a value of say **300** times that corresponding to the rated current (assuming a full load $C^2 R$

loss of 0.3 per cent). Actually, the current will rise at a rate to produce by self-inductive flux a voltage nearly corresponding to the phase voltage, and this self-inductive flux must to a large extent find a path clear of the rotor, as the rotor winding and solid metal form closed circuits hindering any rapid changes of enclosed flux. This stray flux, and the current producing it, will increase steadily in value until the rotor pole has abstracted its flux, and as the next pole comes forward with its flux, which similarly cannot be instantly quenched and must, therefore be largely deflected, the short circuit current will still further increase to produce a stator leakage flux nearly counteracting as far as the stator winding is concerned, the addition of this reversed rotor flux. This case—short circuiting at the zero point of the voltage wave—gives the worst condition as regards magnitude of the stator current, and gives a current wave which for the first few cycles is practically all on one side of the zero line.

Considering the matter in this general way and leaving out refinements, it is clear that the maximum change of current in a half cycle, that is, the amount measured from the top of the positive peak to the bottom of the negative peak, will be that current which can produce a leakage flux nearly equal to twice the pole flux, and that this maximum change of current will be nearly independent of the point on the voltage wave at which the short circuit takes place. But the relative proportions of the current wave that lie above and below the zero line depend upon this feature. To be explicit, refer to a typical single phase short-circuit oscillogram as given in Fig. 1. On this we have drawn a curve through the crests of the positive waves and similarly one through the crests of the negative waves and have extended these back to the axis drawn for the instant of short circuit. The two curves intercept on this axis a length PQ corresponding to 37,000 amperes in this particular case, and our statement is, that for a given machine, short circuited under given conditions, this intercept depends chiefly upon the rotor flux and but little upon the particular point on the voltage wave at which the short circuit takes place; while, on the other hand, the proportions of this intercept above and below the zero line, viz. OP, OQ depend considerably upon the instant of short circuit. Hence, the approximate maximum of the short circuit peak that could occur, were the machine to be short circuited at the least favorable point of the voltage wave (namely, voltage zero) can be ascertained approximately from an oscillogram taken at random, short-circuiting the generator at any point on the voltage wave. This would be represented by the value $P\,Q$ multiplied by the decrement factor for a one-half period, viz. by the ratio cd/ab.

It must be understood that this is true only in a general way, the whole phenomena being affected by varying magnetic saturation of different parts and by actual $C^2 R$ loss in the paths of the short circuit current and eddy currents produced.

This brings forward a question upon which we are in need of some conventional agreement; this Institute might, with advantage formulate one. The " momentary short circuit current" of a generator is nowadays frequently referred to, and discussed, without a proper recognition of the fact that this is not a definite quantity, even for definite values of the load and excitation at the instant of short circuit. In the first place, it will be convenient to always consider this quantity (as finally defined) in terms of the rated current of the machine, and for the sake of uniformity the " rated current " should be the maximum r.m.s. current which the generator is rated to carry continuously. In the next place, the ***peak*** momentary current should not be compared with the r.m.s. rated current, but rather the initial peak value divided by 1.414 should be thus compared. This is consistent with corresponding practice in other lines, as for instance, when an induction motor is specified to take from the line at starting a momentary current not exceeding, say, three times normal current. Finally, what is of real interest is the ***most probable*** ratio of initial short circuit to rated current, when the machine is short circuited at random as regards the position on the voltage wave. If we wish, we can, in addition, very readily have a standard percentage to add to this, which will tell us approximately the highest possible momentary short circuit current ratio under specified conditions. This would correspond to a current which would be approached, within a small percentage, perhaps once in a hundred short circuits.

The most probable momentary short circuit current can be approximately determined from the value of $P\,Q$ referred to above. Having adopted a definition for the momentary short circuit current, it will be convenient to define the " momentary short circuit current ratio " as the ratio between this current and the normal current of the machine for maximum continuous rating.

From the oscillograms given in Figs. 1 to 4, we should say that the generator in question gives, with half voltage excitation at no load, a single-phase short circuit current having a maximum possible peak value of approximately 35,000 amperes, and a probable maximum peak value of 30,000 amperes. As the rated current of this generator is 2400 amperes (r.m.s.) having a peak value of 3400 amperes, we say that the *probable* momentary short circuit current ratio under the conditions of excitation stated above is approximately 8.8 and the *greatest* possible momentary short circuit current ratio under these conditions is 10.3 approximately.

It has been stated above that the stator leakage flux produced on short circuit must be nearly all clear of the rotor because it cannot penetrate suddenly the solid metal of the rotor and the closed field winding. This is largely true but some proportion of the flux will pass into the rotor. This is illustrated by the oscillograms already referred to in which it will be noted that the excitation current, after short circuit, rises in peaks, correspondingly in time to the stator currents peak, to values several times the steady excitation corresponding to the excitation voltage and the resistance of the circuit. Fig. 5 is a reproduction of part of the oscillogram of Fig. 1 with a curve added to show the way in which the flux enclosed by the rotor winding is slowly quenched by the stator current. This curve was deduced from the excitation record.

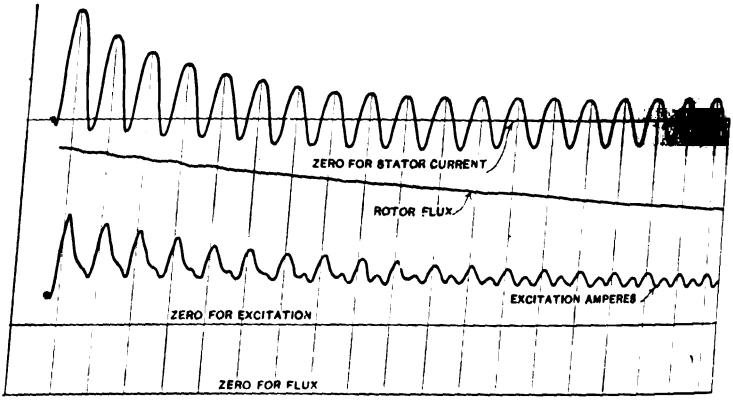

FIG. 5

An idea of the extent to which the flux will penetrate the rotor can be obtained by measuring the impedance of the stator

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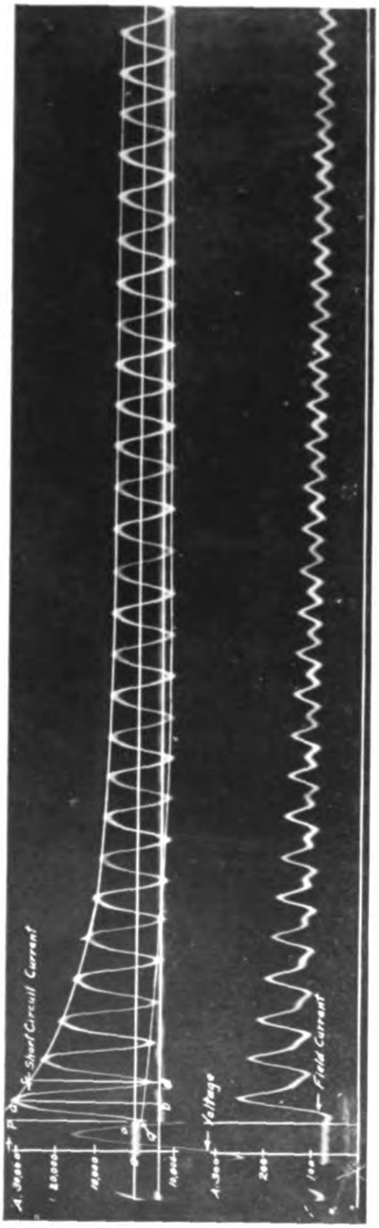

Fig. 1—Stator and Rotor Current of 10,000-kv-a. Turbo-Generator; Single-Phase Short-Circuit at Half Normal Voltage [Field]

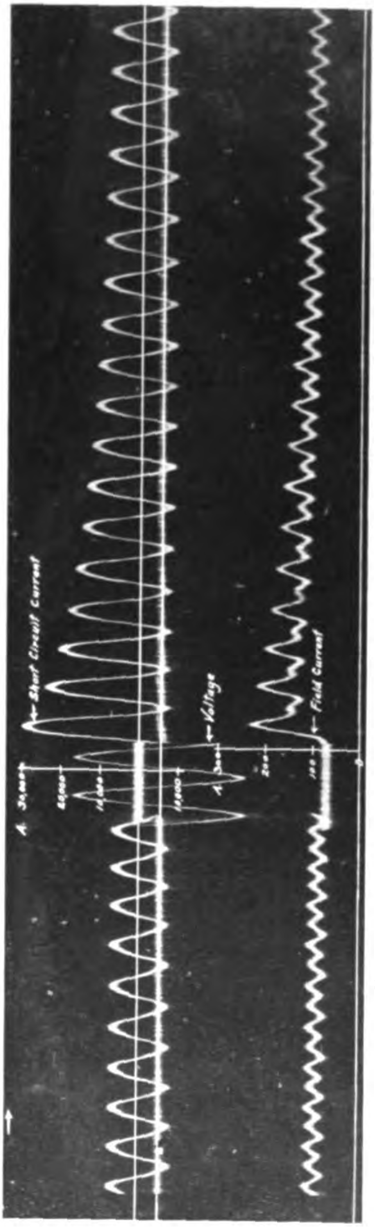

Fig. 2—Single-Phase Short-Circuit at Half Normal Voltage [Field]

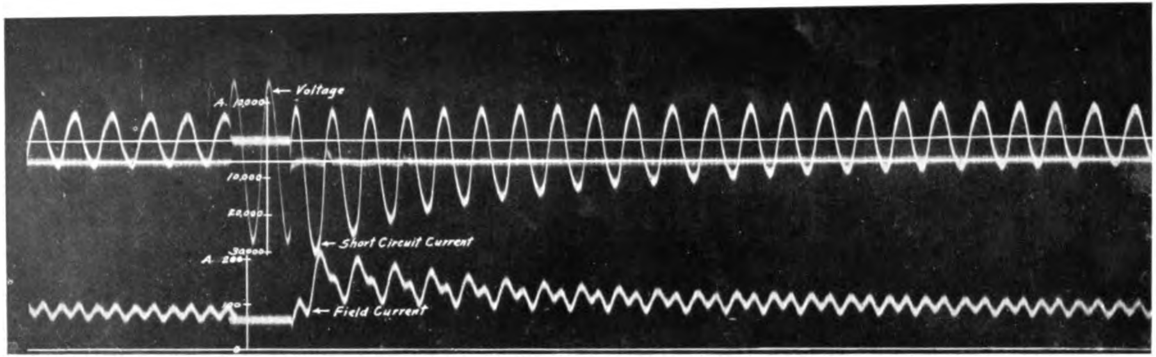

FIG. 3—SINGLE-PHASE SHORT-CIRCUIT AT HALF NORMAL VOLTAGE [FIELD]

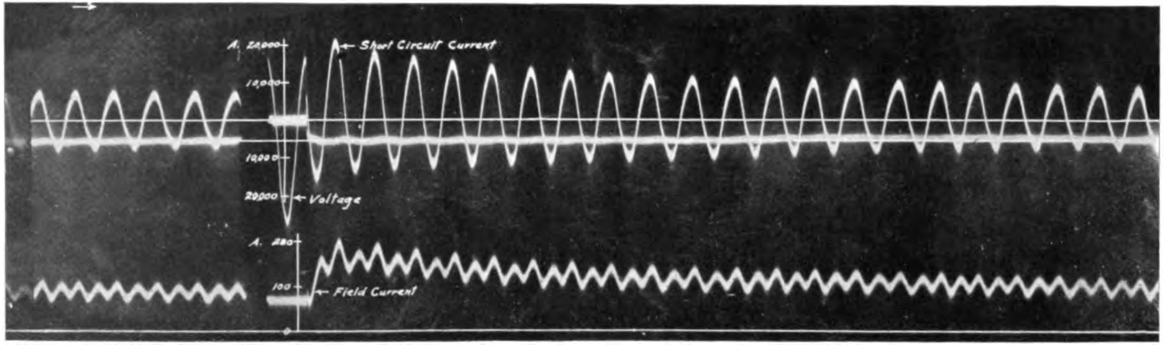

FIG. 4—SINGLE-PHASE SHORT-CIRCUIT AT HALF NORMAL VOLTAGE [FIELD]

with the rotor at rest, applying an external source of current. Such experiments, compared with similar ones taken with the rotor removed, show clearly the magnetic obstruction caused by the presence of the iron.

For instance, we may refer to tests on the machine which furnished the short circuit curves already given, a 10,000-kv-a. 2400-volt, three-phase, 60-cycle, four-pole generator having a solid steel rotor of cruciform section, an air gap of ⅞ in. (22.2 mm.) each side, and stator slots 0.86 in. wide (see Fig. 6 for the type of stator). With the rotor removed, and an external source of 60-cycle current applied to the stator terminals, the impedance was found to be such as to give approximately 8.4 times normal current with full three-phase voltage applied, and 7.3 times normal current when rated voltage was applied across two only of the three terminals, that is, single-phase. Similar tests made on this machine with the rotor in place indicated an impedance which was not strictly independent of the magnitude of the current but which apparently would give about 12 times normal current with three-phase full voltage applied to the stator and about 10½ times normal current single-phase.

Comparing these tests, it will be noted that when the stator core was apparently magnetically short circuited by the rotor with only a ⅞-in. (22.2 mm.) air gap, the impedance of the stator, instead of being increased, was only 70 per cent of that when the iron was removed and the stator flux found its path through the air. The power absorbed in this impedance test amounted to 340 kw. for rated current with the rotor in place, and less than one-sixth of this when the rotor was removed, again showing the effect of the heavy choking currents in the surface of the stationary rotor body.

We see, therefore, that on the occasion of the sudden short circuit of such a turbo-generator a large air gap separating the rotor from the stator will be apt to aid the restriction of the stator current by increasing the available space for the stator and rotor leakage flux, and thus, contrary to the generally accepted idea, changes of proportions which improve the regulation of the generator do not of necessity in every case cause an increase in the momentary short circuit current. However, as pointed out later, it is in general necessary to adopt poor regulation in order to restrict to a reasonable degree the momentary short circuit current, and to obtain other advantages.

From such general considerations as the above, the truth of the following statements will be apparent.

1. The momentary short-circuit current ratio is not directly affected by the frequency to any very large extent, if we consider for instance a 60-cycle turbo-generator operating at different frequencies, except by reason of the smaller penetration of the stator leakage flux into the rotor body at higher frequencies. However, comparing a 25-cycle design with a 60-cycle one, the changed proportions of design, such as the greater pole pitch etc., involve a greater momentary short circuit current ratio with the 25-cycle design.

2. For the same general features of design, a two-pole generator has a larger momentary short-circuit current ratio than a corresponding four-pole machine. However, the difference in this respect between the two- and four-pole machines is not greater than can occur between, say, two four-pole machines of considerably different design.

3. Using a given frame for a definite rating, the momentary short-circuit current ratio is nearly proportional to the square of the flux per pole. *i.e.*, if the number of stator conductors be increased 10 per cent for a given terminal voltage, the momentary short-circuit current ratio is reduced 20 per cent; at the same time the figure representing the full load regulation at unity power factor is increased by an amount depending upon conditions, which may be as much as 50 per cent.

4. The manner in which the momentary short-circuit current ratio increases with the rating can not be stated definitely; it is complicated by a number of features which influence the magnetic proportions of the design.

It has been pointed out that by increasing the number of stator conductors for a given rating, the instantaneous short circuit current is reduced; it might at first be supposed that on account of the increased number of conductors in a group, the mechanical forces on the end connections would nevertheless be increased. However, a little consideration will show that this is not so, and that the forces are decreased by nearly twice the percentage that the number of conductors is increased.

The method of supporting the end connections which is seen in Fig. 6 allows of effective clamping and incidentally provides a large space for leakage flux, while the field around the individual conductors is not excessive; thus the mechanical forces are minimized. The stator shown in this figure was re-

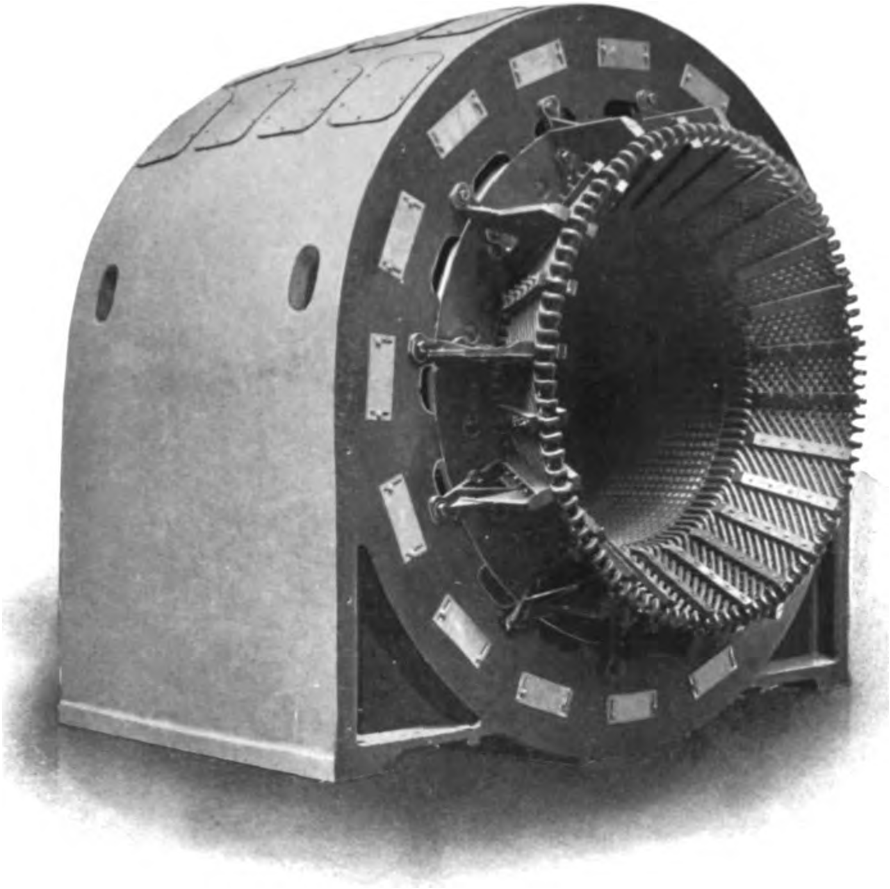

FIG. 6

FIELD]

peatedly short circuited at full voltage, both on one phase and across all terminals, without any signs of distortion of the winding.

A characteristic upon which great stress used to be laid, is close inherent regulation of the generator. It is not hard to see the reasons for abandoning this quality in the present day purchasing specifications for large turbo-generators. In the first place, the price to be paid for it in efficiency, in heavy short circuit currents, in inferior mechanical proportions, and in actual dollars of cost price, was altogether disproportionate to the supposed advantages. In the second place the advantages—for large units at any rate—are found to be of a more theoretical than practical nature. With regard to the cost: In a turbo-generator of say 10,000 kv-a. rating (max.) the friction and windage plus core loss amount to several times the C^2R loss plus excitation, the ratio depending upon speed and design, but varying from perhaps 3 to 7. Hence the point of maximum efficiency is always much outside the rating range, and any increase in variable losses with a reduction of fixed losses causes an increase in efficiency at the operating point. The place where limitations are most severely felt in a large turbo-generator is the rotor, and therefore, to obtain close regulation in such a machine, the flux is of necessity run up higher than it would be without this requirement, hence an impaired efficiency. The increased flux involves a momentary short-circuit current ratio, and mechanical forces on end connections augmented by twice the percentage by which it is itself increased. The rotor limitations preclude the possibility of obtaining the close regulation with the low flux, by means of simply an increased air gap. In several existing installations the consideration of short circuit current alone has necessitated deliberately spoiling the regulation of the generators by inserting external reactance, a procedure which not only does not take advantage of the improvement of efficiency possible with a reduced flux but introduces some, even if small, extraneous losses.

In case of large units the difference between close regulation and poor, will frequently represent the practicability or otherwise of a two-pole as compared with a four-pole design, or four-pole versus six-pole. This incidentally represents an even greater effect on steam consumption due directly to the speed of the turbine. Again the increased flux required for close regulation represents increased rotor weight and changed proportions, which at certain stages will necessitate operation above the critical speed where before a stiff rotor was possible. As regards cost price, the closely regulating machine will be heavier, and while the cost per pound will be slightly less than that of the low flux machine, the total cost will always be somewhat more, except where other sacrifices have been made. We have been assuming that the close regulation is to be obtained by ordinary methods of proportioning. The clever compounding device introduced by Miles Walker, and used to some extent in England for fairly high power factor work, is said to provide the close regulation without any consequent very heavy momentary short circuit current ratio.

With reference to the advantage obtained by close regulation the following points must be borne in mind. Where close voltage regulation is required, an automatic regulator will be used whatever the regulation of the generator. Even with close regulation at unity power factor, that at lower power factors is poor. The size of the stations, and of the units, here discussed is much greater than a few years ago when close regulation was being insisted upon, and while it may be said that fluctuations of load on a section of the bus bars will be correspondingly increased, this fluctuation is not generally so large a percentage of the total rating of the machines on the bus bars. Further, in a large station, if the rapid changes of load are heavy enough to represent a considerable proportion of the connected generator rating, the problem of taking care of the sudden changes of demand for steam will be the principal one, rather than voltage adjustment. As regards parallel operation between machines of different regulations, there is, of course, some hand rheostat adjustment required, if all machines are to share equally the wattless load at varying bus bar loads. But even if the regulation of the parallel units is the same, such hand adjustment will still be necessary, unless the shapes of the saturation curves are also similar. Frequently it is desirable anyway to adjust by hand the division of current load between generators old and new.

The greater rotative speed at which a given output can be handled now, as compared with earlier practice, is largely due to changes of design which increase the available output from a structure of given dimensions rather than to changes which allow of very much larger structures being run at the old speeds. The use of mica and asbestos for rotor insulation allows of operation at temperatures which were near the limit with the older inflammable materials. Modifying our ideas on regulation requirements enables the limitation of stator and rotor to more nearly approach one another, and so on.

As an illustration may be taken some 12,500 kv-a. 750 rev. per min. 25 cycle generators that have for several years done good service on one of our large traction systems. In these machines the stator is 127 in. (3.2 m.) in diameter, 81 in. (2.05 m.) long, and 85.3 in. (2.16 m.) bore, and the flux per pole is about 128 mega-lines. With these stator dimensions the flux would nowadays probably be run up some 30 per cent, or so, but the stator ampere conductors would also be increased to give a maximum rating in the neighborhood of 25,000 kv-a. The full load efficiency would be brought up from 96.4 per cent to 97.8 per cent, each case referring to unity power factor and with friction and windage included among the losses. The regulation at unity power factor, for say 75 per cent of maximum rated load, would be increased from 10 per cent to about 15 per cent. The momentary short-circuit current ratio would not be appreciably increased in spite of the fact that we are dealing with a machine of much larger kilowatt capacity; all the details of design would, of course, be modified to suit, and the machine would be considerably more costly to build.

With the increased ratings prevailing at speeds of 1500 and 1800 rev. per min., it becomes increasingly difficult to provide satisfactory and efficient blowers mounted directly on the rotor. There is the further consideration that the axial length taken by the blowers, and end bell partitioned spaces, increases the span between journals and lowers the critical speed. Some far sighted buyers of large units are now adopting a separately driven external fan, allowing of a very stiff rotor construction. It then frequently remains possible to keep the critical speed above the running speed for large machines too; and the smoothness of operation obtained, even if we magnetically unbalance the rotor by temporarily short circuiting one coil, is a great asset in a large machine. The external blower has several advantages which will be readily seen and which will be accentuated when it becomes standard practice in this country, as in Europe, to install air filters. The writer believes that our central station engineers will follow this practice a few years hence, as it is rational to arrest the dirt on accessible surfaces, whence it can be removed at a cost which is a very small fraction of the expense involved when the dirt is allowed to collect in the generators. One possible alternative to the separate blower handling all the air, is a small external direct connected higher pressure blower producing the necessary low pressure ventilation by an inducing jet in a properly shaped main duct, on the principle of the jet pump. The " high pressure " blowers for these need not necessarily be direct connected, but one could be installed to feed into all the ducts of the station.

A paper to be presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

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DEVELOPMENT OF A SUCCESSFUL DIRECT-CURRENT 2000-KW. UNIPOLAR GENERATOR

BY B. G. LAMME

This paper is not intended to be a theoretical discussion of the principles of unipolar machines; neither is it a purely descriptive article. It is rather a record of engineering experiences obtained, and difficulties overcome, in the practical development of a large machine of the unipolar type. For those who are interested in the designs and development of electrical machinery there may be many points of very considerable interest in this record. Some of the conditions of operation, with their attendant difficulties, proved to be so unusual that it is believed that a straightforward story of these troubles, and the methods for correcting them, will be of some value as a published record.

Two theoretical questions of unipolar design have come up frequently; (1) whether the magnetic flux rotates or travels with respect to the rotor of the stator; and (2) whether it is possible to generate e.m.fs. in two or more conductors in series in such a way that they can be combined in one direction, without the aid of a corresponding number of pairs of collector rings, to give higher e.m.fs. than a single conductor.

To the first question the answer may be made that in the machine in question, it makes no difference whether the flux rotates or is stationary; the result is the same on either assumption. To the second it may be said that when the theory of interlinkages of the electric and magnetic circuits is properly considered, it is obvious that the resultant e.m.f. is equivalent to that of one effective conductor, and therefore it is not practicable to obtain higher e.m.fs. than represented by one conductor, without the use of collector rings or some equivalent device. It has been proposed in the past, by means of certain arrangements of liquid conductors in insulating tubes, to add the e.m.fs. of several conductors in series, but such a scheme does not appear to be a practical device. Therefore, the theoretical considerations being largely eliminated, the author confines himself to the practical side only.

In 1896 the writer designed a small unipolar generator of approximately three volts and 6000 amperes capacity at a speed of 1500 rev. per min. This machine was built for meter testing and the occasion for its design lay in the continued trouble encountered with former machines of the commutator type designed for very heavy currents at low voltages.

The general construction of this early machine is shown in Fig. 1. The rotating part of this machine consisted of a brass casting, cylindrical shaped, with a central web, very similar to a cast metal pulley. The two outer edges of this pulley or ring served as collector rings for collecting the current as indicated in the figure, while the body of the same ring served as the single conductor. The object of this construction of rotor was to obtain a form which could be very quickly renewed in case of rapid wear, as this arrangement would allow a small casting to be made and simply turned up to form a new rotor. However, this renewal feature has not been of very great importance for the rotor of the first machine was replaced only after 12 years' service. This period of course did not represent continuous service, for this particular machine was used for meter testing purposes or where large currents were required only occasionally.

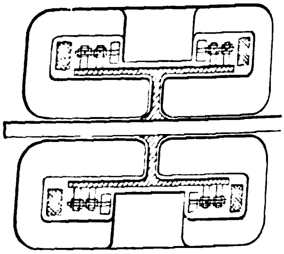

FIG. 1

A number of peculiar conditions were found in this machine. In the initial design the leads for carrying the current away from the brushes were purposely carried part way around the shaft in order to obtain the effect of a series winding by means of the leads themselves. In practice, they were found to act in this manner and, in fact, they over-compounded the machine possibly 30 to 40 per cent. In consequence, it was necessary to shunt them by means of copper shunts around the shaft in the opposite direction.

Shortly after this machine was put in operation there was considerable cutting of the brushes and rings, especially at very heavy currents. It was found that block graphite, used as a lubricant, gave satisfactory results. This machine was operated up to 10,000 to 12,000 amperes for short periods.

The description of the above machine has been gone into rather fully, as it was a forerunner of the 2000-kw. machine which will be described in the following pages. The general principle of construction and the general arrangement of the two parts, or paths, of the magnetic circuit are practically the same in the two machines, as will be shown.

In 1904, due to the rapidly increasing use of steam turbines, the question of building a turbo-generator of the unipolar type was brought up, and an investigation was made by the writer to determine the possibilities. This study indicated that a commercial machine for direct connection to a steam turbine could be constructed, provided a very high peripheral speed was allowable at the collector rings or current collecting surfaces. It appeared that the velocity at such collector surfaces would have to be at least 200 to 250 feet per second, in order to keep the machine down to permissible proportions of the magnetic circuit, and to allow a reasonably high turbine speed. Contrary to the usual idea, the very high speeds obtainable with steam turbines are not advantageous for unipolar machines. For example, while maintaining a given peripheral speed at the current collecting surface, if the revolutions per minute of the rotor are doubled, then the diameter of the rotor collecting rings is halved, and the diameter of the magnetic core surrounded by the collector rings is more than halved, and the effective section of core is reduced to less than one-fourth. The e.m.f. generated per ring or conductor, therefore, on the basis of flux alone, would be reduced to less than one-fourth, but allowing for the doubled revolutions per minute, it becomes practically one-half.

On the other hand, if the revolutions are reduced, while the speed of the collector ring is kept constant, then the e.m.f. per ring can be increased, as the cross section of the magnetic circuit increases rapidly with reduction in the number of revolutions. But at a materially reduced speed, the total material in the magnetic circuit becomes unduly heavy. In consequence, if the speed is reduced too much, then the machine becomes too large and expensive, while with too great an increase in speed, the e.m.f. per ring becomes low or the peripheral speed of the rings must be very high. It is desirable to keep the number of collector rings as small as possible, for each pair of rings handles the full current of the machine, and therefore any increase in the number of rings means that the full current must be collected a correspondingly large number of times. Therefore, it works out that the range of speeds, within which the unipolar machine becomes commercially practicable, is rather narrow.

In 1906, an order was taken for a 2000-kw. 1200-rev. per min., 260-volt, 7700-ampere unipolar generator to be installed in a portland cement works near Easton, Pa. The fact that it is a cement works should be emphazised, as having a considerable bearing on the history of the operation of this machine, as will be shown later.

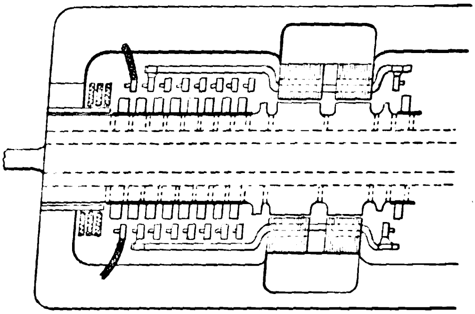

FIG. 2

This 2000-kw. machine does not represent any theoretically radical features, being similar in type to the smaller machine already described, but modified somewhat in arrangement to allow the use of a large number of current paths and collector rings. The general construction of this machine is indicated in Fig. 2.

The stator core and the rotor body are made of solid steel, the stator being cast, while the rotor is a forging. There are eight collector rings at each end of the rotor, the corresponding rings of the two ends being connected together by solid round conductors, there being six conductors per ring, or 48 conductors total. In each conductor is generated a normal e.m.f. of 32.5 volts, and with all the rings connected in series, the total voltage is 260.

The stator core, at what might be called the pole face, is built up of laminated iron, forming a ring around the rotor. This was laminated in order to furnish an easy method for obtaining the stator slots in which the conductors lie which connect together the brushes or brush holders for throwing the pairs of rings in series. The slots in the stator laminations were made open, as indicated in Fig. 3, in order to readily insert the stator conductors. There are 16 slots in this ring, and in each slot there is placed one large solid conductor.

As first assembled, non-metallic wedges were used to close these slots, but later these were changed to cast iron for reasons which will be explained later.

The rotor core consists of one large forging, as indicated in Fig. 2. Lengthwise of this rotor are 12 holes for ventilating purposes originally $2\frac{3}{4}$ in. diameter. Each of these holes connected to the external surface by means of nine $1\frac{3}{8}$ in. radial holes at each end of the rotor, these holes corresponding to mid-positions between the collector rings. It was intended to take air in at each end of the rotor and feed it out between the collector rings for cooling. In addition, as originally constructed, there was a large enclosed fan at each end, as indicated in Fig. 4. These fans took air in along the shaft and directed it over the collector rings parallel to the shaft. The object of this was to furnish an extra amount of air for cooling the surfaces of the rings, and the brushes and brush holders, as it was estimated that the brushes and brush holders themselves could conduct away a considerable amount of heat from the rings by direct

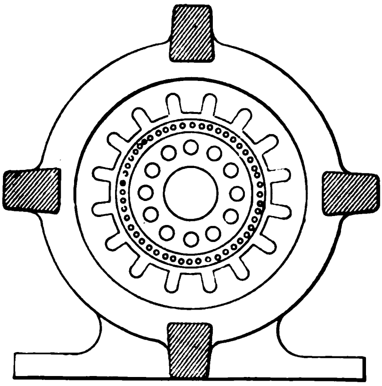

Fig. 3

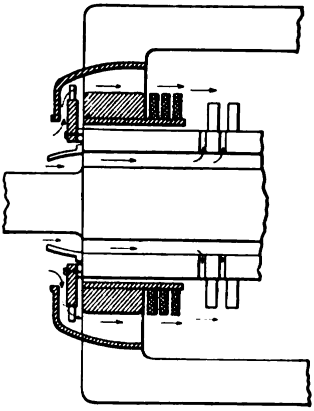

Fig. 4

contact, and that the cooling air from the fans, circulating among the brush holders, would carry away this heat. These fans were removed during the preliminary tests, for reasons which will be given later.

The rotor collector rings consisted of eight large rings at each end, insulated from the core by sheet mica, and from each other by air spaces between them. Each ring has 48 holes parallel to the shaft. These holes are of slightly larger diameter than the rotor conductors outside their insulation. Six holes in each ring were threaded to contain the ends of six of the conductors which were joined to each ring. The six conductors connected to each ring were spaced symmetrically around the core. Fig. 5 shows this construction.

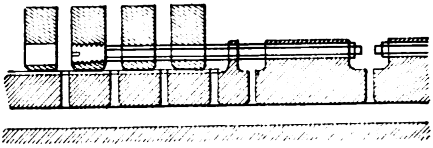

FIG. 5

The rotor conductors, 48 in number, consist of one in. copper rods, outside of which is placed an insulating tube of hard material. Each conductor, in fact, consists of two lengths arranged for joining in the middle. The outer end of each conductor is upset to give a diameter larger than the insulating tubes, and a thread is cut on this expanded part. After the rings were installed on the core, the rods were inserted through the holes to the threaded part of a ring and were then screwed home.

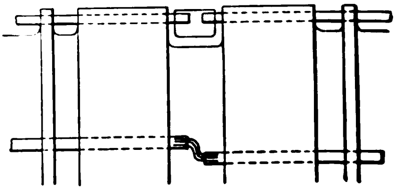

FIG. 6

At the middle part of the rotor core, a groove is cut as shown in Fig. 6. Into this groove the two halves of each conductor project. These two ends are then connected together by strap conductors in such a way as to give flexibility in case of expansion of the conductors lengthwise. This arrangement is also shown in Fig. 6.

With this arrangement there is no possibility whatever of the conductors turning after once being connected. There is a series of holes from the axial holes through the shaft to this central groove, for the purpose of allowing some ventilating air to flow over the central connections.

As originally constructed, the conductors passed through completely enclosed holes near the surface of the rotor core, as indicated in Fig. 7. This construction was afterwards modified to a certain extent. The face of the rotor at this point was also solid, as originally constructed. This was afterwards changed, as will be described later.

The collector rings, as originally constructed, consisted of a base ring with a wearing ring on the outside, as shown in Fig. 8. Both rings were made of a special bronze, with high elastic limit and ultimate strength. On the preliminary tests these rings showed certain difficulties and required very considerable modifications, and several different designs were developed during the preliminary operation, as will be described.

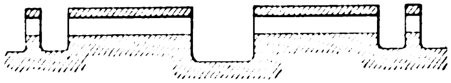

FIG. 7

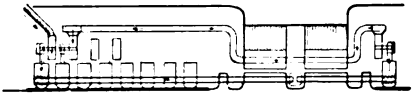

FIG. 9

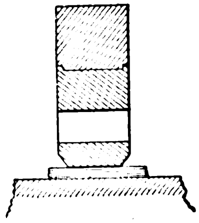

FIG. 8

The eight sets of brush holders at each end are carried by eight copper supporting rings. These supporting rings are insulated from the frame of the machine but are connected in series by means of the conductors through the stator slots. There are 16 brush holders studs per ring and two brush holders per stud, each capable of taking a copper leaf brush $\frac{3}{8}$ in. wide by $1\frac{3}{8}$ in. thick. These brush holders are spaced practically uniformly around the supporting rings. The supporting copper rings are continuous or complete circles, so that the current collected from the brushes are carried in both directions around the ring. There are two conductors carried from each ring through the stator slots to a ring on the opposite side of the machine, in order to connect the various brush holders in series. The arrangement is illustrated in Fig. 9.

The above description represents the machine as originally constructed and put on shop test. From this point on, the real story begins. Various unexpected troubles developed, each of which required some minor modification in the construction of the machine and, moreover, these troubles occurred in series. that is, each trouble required a certain length of time to develop, and each one was serious enough to require an immediate modification in the machine. In consequence, the machine would be operated until a certain difficulty would develop; that is, that trouble would appear which took the least time to develop. After it was remedied, a continuation of the test would show a second trouble which required a remedy, and so on. Some of these troubles were of a more or less startling nature, as will be described later.

This machine, after being assembled according to its original design, was operated over a period of several weeks in the testing room of the manufacturing company. It was operated both at no load and at full load, and a careful study was made of all the phenomena which were in evidence during these tests.

The machine was first run at no-load without field charge to note the ventilation, balance, and general running conditions of the machine. The ventilation seemed to be extremely good, especially that due to the fans on the ends of the shaft. The noise, however, was excessive,—so much so that anyone working around the machine had to keep his ears padded. At first it was difficult to locate the exact source of this noise, but it was determined that the end fans were responsible for a considerable part of it.

On taking the saturation curve of the machine, it was found to be extremely sluggish in following any changes in the field current. The reason for this sluggishness is obvious from the construction of the machine, each magnetic circuit of the rotor core being surrounded by eight continuous collector rings of very heavy section, and also by eight brush holder supporting rings of copper of very low resistance. These rings, of course, formed heavy secondaries or dampers which opposed any change in the main flux. The total effective section of these rings was equivalent in resistance to a pure copper ring having a section of 49 sq. in. One can readily imagine that such a ring would be very effective in damping any sudden flux changes. This sluggishness of the machine to changes in flux, however, was not an entirely unexpected result.

The saturation curve showed that the machine could be carried considerably higher in voltage than originally contemplated, for apparently the magnetic properties of the heavy steel parts were very good, and it was possible to force the inductions in these parts to much higher density than was considered practicable in working out the design. This gave considerable leeway for changes which later were found to be necessary.

In taking the saturation curve, the power for driving the machine was measured and it was found that there were practically no iron losses in the machine; that is, at full voltage at no-load the total measured losses were practically the same as without field charge. This apparently eliminated one possible source of loss which was anticipated, namely, that due to the large open slots in the stator pole face, these slots being very wide compared with the clearance between the stator and rotor.

After completion of this test the machine was then run on short circuit. Apparently, as there was no iron loss shown in the no-load full voltage condition, the short circuit test with full load current should cover all the losses in the rotor which would be found with full load current at full voltage. Experience afterward proved this assumption to be correct, for in its final form the machine would operate under practically the same condition as regards temperature, etc., at full voltage as it would show at short circuit, carrying the same current, the principal difference being the temperature of the field coil.

It was in this short circuit temperature run that the real troubles with the machine began. The measured losses, when running on short circuit, were somewhat higher than indicated by the resistance between terminals times the square of the current. These extra losses were a function of the load and increased more rapidly with heavy currents. The measured power indicated that these excess losses were principally due to eddy currents. However, the total losses indicated in these preliminary tests, although somewhat higher than calculated, were still within allowable limits, as considerable margin had been allowed in the original proportions to take care of a certain amount of loss. It was therefore considered satisfactory to go ahead with the short circuit tests, and in making these it was the intention to operate long enough to determine the necessary running conditions as regards lubrication, heating, etc.

As mentioned before, the original collector rings of the machine each consisted of a base ring upon which was mounted a secondary or wearing ring, it being the intention to have this latter ring replaceable after it was down to the lowest permissible thickness, as it would be rather expensive and difficult to replace the base ring which carried the rotor conductors. As the inner ring was shrunk on the core and the outer ring was shrunk on over the base ring, with a very small shrinkage allowance, it was considered that the outer ring was in no danger of loosening on the inner ring, especially as both rings, being of bronze, and in good contact, should heat each other at about the same rate. This assumption, however, was wrong. The machine was put on short circuit load of about 8000 amperes early one evening and an experienced engineer was left in charge of it until about midnight. Up to that time the machine was working perfectly, with no under heating in the rings and no brush trouble, although vaseline lubrication was used. About midnight the engineer left the machine in charge of a night operator, and at about three o'clock in the morning this operator saw the brushes beginning to spark and this very rapidly grew worse, so that in a very few minutes he found it necessary to shut the machine down. An examination then showed that several of the outer rings had shifted sideways on the base ring, as indicated in Fig. 10. One of these rings had even moved into contact with a neighboring ring so as to make a dead short circuit on the machine. It was also noted that all the rings which loosened were on one side of the machine, and that the surfaces of the rings exposed to the brushes were very badly blistered. The brushes also were in bad shape, indicating that there had been excessive burning for a short time. An investigation of the loose rings showed that they had loosened on their seats on the inner or base rings. Investigation then showed that a temperature rise of 70 to 80 deg. cent., combined with the high centrifugal stresses, would allow the rings to loosen very materially. It was then assumed that as the ring had heated up, bad contact had resulted between the inner and outer rings and this, in turn, had caused additional heating, so that the temperature rose rather suddenly after bad contact once formed. It developed later that this was probably not the true cause of the trouble, but at the time it was considered that the remedy for the trouble was in the use of rings which could be shrunk on with a greater tension.

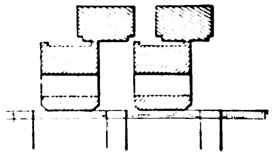

Fig. 10

It was then decided to try steel outer rings instead of bronze on the end where the bronze rings had loosened. However, upon loading the machine, after applying the steel rings, a new difficulty was encountered. It was found that the loss was very greatly increased over that with the bronze rings. This loss was so excessive as to be prohibitive, as far as efficiency was concerned, and also the tests showed excessive heating of the rings and of the machine as a whole. Also, there were continual small sparks from the tips of the brushes, these sparks being from the iron itself, as indicated by their color and appearance. However, during the time these rings were operated there did not seem to be any undue wear of either the brushes or the rings, but obviously there was continued burning, as indicated by the sparks. With these steel rings it was found to be impossible to operate continuously at a current of 8000 amperes, due to the heating of the steel rings in particular and everything in general. At a load of 6000 amperes the loss was materially reduced and it was possible to operate continuously but with very high temperatures. The tests showed that, with the steel rings, at full rated current, the loss was approximately 200 kw. greater than with the bronze rings, or about 10 per cent of the output. With both ends equipped with steel rings, this would have been practically doubled.

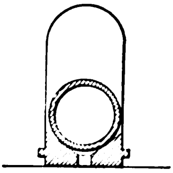

FIG. 11

While this was recognized as an entirely unsatisfactory operating condition, yet it allowed the machine to be run for a long enough period to determine a number of other defects which did not develop in the former test. One of these defects was an undue heating of the rotor pole face. This was obviously not due directly to bunching of the flux in the air gap on account of the open stator slots, for this heating did not appear when running with normal voltage without load. Further investigation showed that this was apparently due to some flux distorting effect of the stationary conductors in the stator slots, which carried about 4000 amperes each at rated load. On account of ample margin in the magnetizing coils the air gap was then materially increased, with some benefit. A further improvement resulted in the use of magnetic wedges, made of cast iron, in place of the non-magnetic wedges used before. These wedges are illustrated in Fig. 11. This produced a further beneficial effect, but there was still some extra heating in the pole face. Cylindrical grooves alternating ½ in. and 1 in. deep and about $\frac{1}{8}$ in. wide, with a $\frac{1}{4}$ in. web of steel between, were then turned in the pole face. The resultant pole face was therefore crudely laminated, as shown in Fig. 12. Also, on account of an apparent local heating of the metal bridge over the rotor slots, a narrow groove was cut in the closed bridge above each rotor slot, thus changing it to a partially open slot, as shown in the figure. This effectively eliminated the excess loss in the rotor pole face. This, however, led to another unexpected difficulty, which will be described later.

After this trouble was cured, the short circuit test was continued with a current of about 6000 amperes. After a considerable period of operation, a very serious difficulty in the operation of the machine began to show up, namely, trouble with lubrication. At first the lubrication was vaseline fed on to the rings by lubricating pads. This was apparently very effective for awhile, but eventually it was noted that slight sparking began, which, in some cases, would increase very rapidly and, in a comparatively short time, became so bad that the rings or brushes would become badly scored or blistered. Examination of the sparking brushes showed a coating of black " smudge " over the surface which seemed to have more or less insulating qualities. A series of tests then showed that whenever sparking began, the contact drop between a brush and the collector ring was fairly high and this drop increased as the sparking increased. For instance, it was found that on good, clean surfaces, the voltage drop between the brushes and the ring might be 0.3 to 0.5 volt. As each brush carried about 250 amperes at full load, this represented 75 to 125 watts per brush. When this contact resistance rose to about one volt, noticeable sparking would begin, the watts being, of course, proportionally higher, and when the contact drop became as high as two volts, representing about 500 watts per brush, very bad burning of the brushes and rings was liable to occur. A series of tests then showed that vaseline, or any other lubricating oil, would tend to form a coating over the brush contact and this coating would gradually burn, or be acted upon otherwise by the current, so that its resistance increased and the black smudge was formed which had more or less insulating qualities.

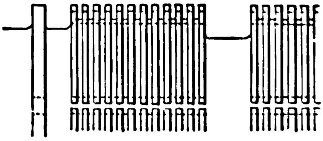
FIG. 12

A great number of tests were then carried out with various kinds of lubricants and it was found that anything of an oil or grease nature was troublesome sooner or later, as the smudge was formed on the brush contact. Then graphite, formed into cakes or brushes by means of high pessure, was tried on the rings and the results were very favorable compared with anything used before. In fact, the tests indicated that soft graphite blocks or brushes could furnish proper lubrication for the rings. The graphite is a conducting material, and a coating of it on the brush contact does not materially increase the resistance of the contact. This was supposed to have practically settled the question of lubrication and brush contact trouble, but experience later gave an entirely new turn to this matter.

While these tests were being carried on, a study of the ventilation of the machine was being made. The tests indicated that the end rings, that is, those next to the exciting coils, were considerably cooler than those near the center of the machine. However, as there were excessive losses and heating in the steel rings themselves, it was not possible to make any material improvement until the rings were changed.

The steel rings at one end of the rotor, and the bronze rings at the other end, were then removed and a second set of bronze rings was tried. These rings were specially treated in the manufacture so that the elastic limit was very high, and they were put on much tighter than in the former case. The load tests were then continued and the excess losses were again measured at various loads. It was found that the losses were very small compared with those of the steel rings, thus verifying the former results. The temperatures of the rings were much lower than with the steel, but it was found that the heating of the rings was unequal. It was finally determined that this unequal heating was due to the large external blowers which were driving the air over the rings in such a way as to heat those next to the center of the rotor to a much higher temperature than those at the outer ends. It was assumed at first that the air entering the axial holes through the core and blowing out between the rings as shown in Fig. 1, was more effective on the outer rings, and that this possibly caused the difference in temperatures. However, the radial holes at the outer ends were closed, and this made but little difference. The axial holes were then closed, and while the temperatures of the rings, as a whole, were increased, about the same difference as before was found between the end rings and the center ones.

It was then decided to remove the two large blowers to determine whether some other method of ventilation would be more effective. When this change was made the windage of the machine was greatly reduced and there was greater uniformity in the temperatures and the average temperature of the rings was only about 10 deg. higher than with the fans. Moreover, the windage loss was only about one-seventh as great as before, although the average temperature rise was not much higher, which indicated that the ventilation through the rotor holes was much more effective than that due to the blowers. In consequence, it was decided to increase the size of the axial holes through the rotor core from 2¾ in. to 3¾ in. diameter, and to "bell-mouth" them at their openings at the ends, in order to give a freer admission of air to the holes. When this was done it was found that the temperatures of the rings were lower than in any of the preceding tests, and moreover, they were fairly uniform. Also after the removal of the blowers, the objectionable noise, already referred to, was largely eliminated, so that it was not disagreeable to work around the machine. The graphite lubrication was continued with the bronze rings, on this test, and no difficulty was encountered, although the machine was operated for very considerable periods at approximately 8000 amperes.

On the basis of these tests, the machine was shipped to its destination and put in service. Then the real difficulties began—difficulties which were not encountered in the shop tests, principally because the conditions under which the machine operated in service were radically different from those at the shop, and also, because the shop test had not been continued long enough. This machine was operated in service, although not regularly, for a period of about two months, being shut down at times due to difficulties outside of the generating unit itself. However, this period of operation of the generator was suddenly ended by the stretching of one of the outer collector rings, which loosened it to such an extent that it ceased to rotate with the inner ring. This required the return of the rotor to the manufacturer.

This two months' operation gave data of great practical value, and in consequence, a number of minor difficulties were eliminated in the repaired rotor.

Upon the return of the rotor to the shop, an examination of the collector rings showed that the separate shrunk-on type of ring was not practicable with any design of ring then at hand. Therefore, it was decided to make the collector rings in one solid piece with a very considerable wearing depth. This necessitated the removal of all the base rings and, in fact, it required a complete dismantling of the entire rotor winding. As the outer ring had loosened, there was a possibility of the base rings loosening in the same way, and therefore it was considered necessary to apply some scheme for preventing this loosening in case of sudden heating and expansion of any of the collector rings. It was then decided to apply some form of spring support underneath these rings, which could follow up any expansion in such a way as to keep the rings tight under any temperature conditions liable to be met with in practice. The spring support used consisted of a number of flat steel plates arranged around the rotor core, as indicated in Fig. 13. These plates were of such length and stiffness that a very high pressure was required to bend them down to conform with the rotor surface. These plates were arranged around the rotor core and drawn down with clamp rings until they fitted tightly against the mica. The collector ring was highly heated and slipped over the springs, the clamps being removed as the ring was slipped on. Tests were made to find at what temperature such a ring would loosen. While the best arrangement without springs would loosen at about 100 to 125 deg. cent., it was found that a ring supported, in the above manner, was still fairly tight at 180 deg. cent., which was far above any temperature which the machine would attain under any condition. It may be said here that, after several years' operation, this construction still appears to be first class, and no loosening of any sort has occurred.

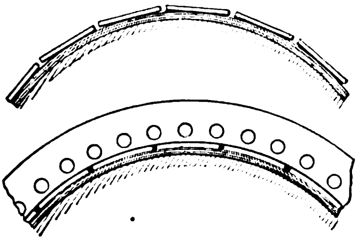

FIG. 13

In removing the winding from the rotor, it was discovered that the insulating tubes over the rotor conductors had traveled back and forth along the rods a certain amount. This travel, if continued for a long enough period, would apparently have injured the insulation, although no trouble had yet developed. Apparently, during heating and cooling, the expansion and contraction of the rods would carry the tubes with them lengthwise a very small amount. The tubes would then seat themselves in the supporting rings or core and would not return to their original positions. It was found that in the slotted pole face already described, the webs or laminations of metal overhanging the rotor slots would hold the tube when the rod was traveling in one direction, but would sometimes allow the tube to move slightly when the rod traveled in the other direction, so that there was a sort of extremely slow ratchet action taking place. It was evidently necessary to have the tubes fit rather tightly in the retaining or supporting holes in the rings and the core, and to have the rods fit rather loosely in the tubes. Also, it appeared that shellac or other "gummy" material on the inner surface of the insulating tubes, was harmful, for wherever shellac was present the insulating tube always stuck to the rod and would tear at either side of such place. In consequence, the new set of tubes was made with a dry, hard finish on both the outside and the inside, and the inside surface was also paraffined. This, when carried out properly, served to remedy this trouble.

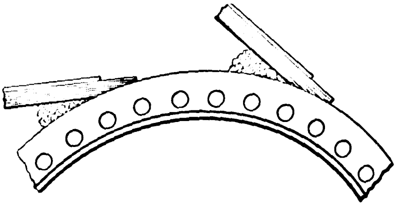

FIG. 14

The reconstructed rotor, with the solid collector rings, was shipped to the customer and the service was continued. After operation for a considerable time, certain extremely serious difficulties appeared. One of these was brush trouble, and another was undue wear of the rings.

The brush trouble was a most discouraging one. The machine was located in an engine room adjacent to a rock-crushing building. Fine dust was always floating around the machine and, this dust continuously passing through the machine tended to form a deposit immediately behind the brushes as shown in Fig. 14. This dust packed in rather solidly behind the brush, due to the high speed of the rings, and eventually it tended to lift the brushes away from the rings. It also showed a tendency to get under the brush contact, with consequent increased resistance of contact. Frequent removal and cleaning of the brushes was impracticable, as they were not sufficiently accessible to do this readily. This rock dust, packed behind the brushes, also had a scouring or grinding action on the rings themselves. Accompanying this was an undue rate of wear of the rings. This, however, was not entirely mechanical wear, as it appeared also to be dependent upon the current carried and was, to some extent, due to a burning action under the brush which tended to eat away the surface of the rings. However, while the undue wear was not altogether due to dust back of the brushes, yet this accumulation of dust appeared to have a very harmful action on the machine. Various methods were considered for overcoming this collection of dust, one of which consisted of enclosed air inlets to the machine, fitted with screens for sifting out the dust. This lessened the trouble to some extent, but it was evident that it would not cure it entirely, as the entire machine was so located that dust could come in around the brush holders without going through the ventilating channels.

The method finally adopted for overcoming the difficulty of accumulation of dirt was rather startling. It was casually suggested that the copper leaf brushes be turned around so that *the rings would run against the brushes*, so that the dirt or dust over the rings would be " skimmed off " by the forward edge of the brushes. This obviously would prevent the collection of dirt, but the question of running thin leaf copper brushes on a collector ring operated at a speed of about 220 feet per second (or 13,200 feet per minute) looked like an absurdity to any one with experience in electrical machinery, so that we all hesitated at first to consider the possibility of it. However, as something had to be done, the writer suggested to the engineer in charge, that he change the brushes on one of the rings so that they would be inclined against the direction of rotation. This gave no trouble and the other brushes were then changed to the same direction and the operation ever since has been carried on with this arrangement. To the writer this has always seemed an almost unbelievable condition of operation, but as there has not been a single case of trouble from this arrangement during several years of operation, one is forced to believe that it is all right. This change entirely overcame the trouble from accumulation of dirt. However, it did not entirely cure the burning of the brushes and rings above described, but rendered the matter of lubrication somewhat easier than at first.

As to the other serious trouble, it was mentioned that there was a burning action under the brushes which tended to " eat " or " wear " away the surface of the rings. This also tended to burn away the brush surfaces, the amount of burning in either case depending, to a considerable extent, upon the direction of the current. At one side of the machine the brushes would wear more rapidly, while at the other side the rings would wear faster. The polarity of the current was influential in this action. Particles of the metal appeared to travel in the direction of the current; that is, where the current was from the ring to the brushes, the ring would wear more rapidly, while the brush would show but little wear, while at the other end of the machine, the opposite effect would be found. However, the particles of metal taken from the ring did not deposit, or " build up," on the brushes.

During all this operation, graphite had been used for lubrication. In the earlier stages, powdered graphite compressed into blocks, had been used. Later it was found that very soft graphite brushes in insulated holders would give ample lubrication for the rings. However, even with this lubrication and the removal of the dirt trouble, there was still an appreciable burning of the brushes and rings as indicated by the more rapid wear of the rings at one end of the rotor, and of the brushes at the other end. Extended tests showed that this burning was a function of the contact drop between the brushes and the rings. Neither the rings nor the brushes would burn appreciably if the contact drop between the brushes and the ring could be kept very low. When this drop became relatively high (about one volt), the rings or brushes would show an undue rate of wear. It was found also that, after a considerable period of operation, it was very difficult to obtain a low brush contact drop, as the brush wearing surface became coated with a sort of " smudge," which seemed to have resisting qualities. An analysis of this coating showed a very considerable amount of zinc in it, and it was determined that the zinc in the collector rings was burning out and forming an insulating coating on the brush contacts. The remedy for this condition was the application of some cleaning agent which would chemically act on the smudge and dissolve it or destroy its insulating qualities. The right material for this purpose was found to be a weak solution of muriatic acid— about 4 per cent in water. When this was applied to the rings by means of a " wiper," at intervals, the brush contact drop could be reduced to a very low figure— frequently to 0.1 or 0.2 of a volt, and the rings would take on a very bright polish. Also, while this low contact drop was maintained it was found that the rings showed an almost inappreciable rate of wear. However, one set of rings continued to wear somewhat faster than the other. This difficulty of unequal wear of the two sets of rings was overcome by arranging a switch so that the polarity of the two ends of the machine could be changed occasionally.

The temperature of the machine was reduced by the above treatment of the rings. Obviously, part of the heat was due to the loss at the brush contacts, which, of course, was reduced directly as the contact drop was reduced.

The machine was now running quite decently with comparatively heavy loads, from 7000 to 10,000 amperes, and the only trouble was in several minor difficulties which were then taken up, one at a time, in order to ascertain a suitable remedy. These difficulties, however, were not interfering with the regular operation of the machine.

One of the difficulties which finally developed was due to stray magnetic fluxes through the bearings. These fluxes, passing out through the shaft to the shell of the bearing, constituted, in themselves, the elements of a small unipolar machine, of which the bearing metal served as collecting brushes. The e.m.f. generated in the shaft was a maximum across the two ends of the bearing. Consequently the current collected from the shaft by the bearing metal should have been greatest near the ends of the bearing, and least at the center. This was the case as indicated by the appearance of the bearing itself, which showed evidence of pitting near the ends but none at the center.

To remedy this trouble, a small demagnetizing coil was placed outside the stator frame, at each end of the rotor, between the rotor core and the bearings. These coils were excited by direct current which was adjusted in value until practically zero e.m.f. was indicated on the shaft at the two ends of each bearing. This indicated that the unipolar action was practically eliminated. This arrangement has been in use ever since it was installed, and no more trouble of any sort has been encountered from local currents in the bearings or elsewhere.

Some of the brushes did not show as good wearing qualities as desired and various experiments were made with different combinations of materials and various thicknesses and arrangement of the brush laminæ. Brass leaf brushes were tried; also, mixtures of copper, brass, aluminum and various other leaf metals in combination. None of these showed any better than the thin copper leaf brush. The tests finally showed that such a brush, very soft and flexible, with a suitable spring tension, would give very satisfactory results. Also instead, of two brushes side by side, a single brush, covering the full width of a ring, was found to be more satisfactory. Some tests were also made with carbon brushes, consisting of a combination of carbon or graphite combined with some metal, such as copper, in a finely divided state. These brushes were claimed to have a very high carrying capacity and also to have a certain amount of self-lubrication. A set of these brushes was tried on one of the rings, but lasted only for a very short time. The apparent wear was rapid, but it is not known whether this was due to the very high speed of the collector rings, or rapid burning away of the brush or the inability of this type of brush to quickly follow any inequalities of the collector rings. This test was abandoned in a comparatively short time.

After getting rid of the old troubles, a new and unexpected one had to appear. For some unknown reason, the insulating tubes on the rotor conductors began to break down; also grounds occurred between the collector rings and the core.

On account of the delay required in making any changes in the rings or rotor winding, the customer arranged with the manufacturer to have a new rotor built as a reserve, as it was obvious that sooner or later there would have to be considerable reconstruction of the insulation on the first rotor due to unexplained short circuits and grounds. A new rotor was at once constructed, embodying all the good features of the first rotor, with some supposedly minor improvements. The old rotor was then removed for investigation and repairs. The cause of the breakdowns of the insulation on the tubes was then discovered. The air entering through the axial rotor holes and passing out through the radial holes between the rings, carried fine particles of cement or crushed stone dust and this had " sand-blasted " the under side of the tubes. When the rotor had been operated during the preliminary two months' period, previously described, before the replacement of the rings, no evidence of this sand-blasting had been visible. Investigation showed that the insulating tubes in the former winding had been made with a fullerboard base, which is rather soft and fibrous in its construction. The tubes on the second winding had been made with " fish " paper instead of fullerboard, in order to give a hard finish on the inside and outside. It was due to this hard material that the troubles from sand blasting occurred. However, fish paper tubes were superior to the fullerboard in strength and other qualities, and as they were inferior only, in this one characteristic, they were used again in rewinding the rotor, but wherever the tubes were exposed in passing from one ring to the next, they were taped over with several layers of soft tape whch was also sewed. This gave a soft finish which would resist sandblasting, and no trouble from this source has occurred for several years.

From the breakdowns to ground, it was evident that an entire replacement of the rings was necessary in order to repair the mica bush or sleeve lying beneath the rings. This required the removal of the entire rotor winding and rings. It was found that cement dust coming up through the radial holes had sifted in through various crevices or openings around the holes and that, finally, conducting surfaces and paths were formed which allowed the current to leak to ground sufficient to eventually burn the insulation. Therefore, when replacing the mica sleeve over the rotor, extra care was taken to fit insulating bushings at the top of the radial holes in such a way as to seal or close all joints, thus allowing no leakage paths between collector rings and the body of the core. This is shown in Fig. 15. No further trouble has occurred at this point.

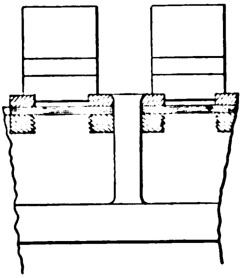

FIG. 15

In removing the collector rings for these repairs, it was found that the flat spring supports shown in Fig. 13 had been entirely effective and there was no evidence whatever of any disturbance of the rings on the core, and there was no injury to the mica, such as would be shown by any slight movement. The rings were also very tight so that it took a very considerable temperature to loosen them sufficiently for removal.

In view of the delay and expense of repairing one of these rotors when the collector rings had to be removed, with the possibility of damaging the insulating tubes over the conductors, and the insulating bush over the core, it was then decided that a movable wearing ring was practically necessary in order to make this machine a permanent success. Therefore, the problem of a separate outside wearing ring, as originally contemplated, was again taken up. The difficulty, already described, of the zinc burning from the rings and forming a coating on the brushes, indicated that some other material, without such a large percentage of zinc, should give better results. The difficulty was to obtain such a material, with suitable characteristics otherwise. All data at hand showed that rings, with desirable characteristics electrically, did not have the proper elastic limits, or proper expansion properties when heated. In other words, when such rings were shrunk on the base or supporting ring they would stretch to such an extent, when cooled, that they would become loose again with very moderate increase in temperature. The solution of this problem of a separate ring construction was found in the use of some spring arrangement underneath the outer ring which would still keep it tight on the inner ring even when hot. The spring arrangement used under the inner rings, as shown in Fig. 13 was then applied with certain modifications. In order to get good contact between the inner and outer rings for carrying the current, each of these steel springs or plates was covered by a thin sheet of copper as shown in Fig. 16. While each copper sheet was of comparatively small section, the large number of springs used gave sufficient total copper to carry the current from the outer to the inner or base ring without any danger of current passing through the spring plates themselves. This arrangement was used in reconstructing this rotor and has proven entirely successful.

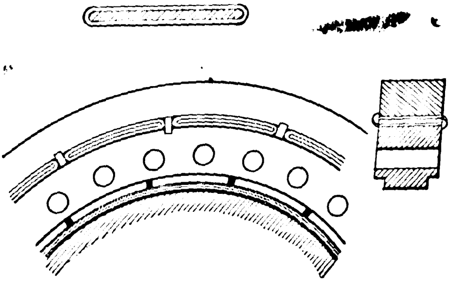

FIG. 16

In order to determine the effects of various materials without zinc, or with but a small quantity of it, a number of rings were fitted up on a test rig and were operated for long periods with currents, up to 12,000 amperes in some cases. In these tests, four different kinds of material were used, all of them representing different mixtures of copper with a small percentage of other materials but with little zinc in any of them. It was feared that copper brushes on the copper rings would not work satisfactorily, but while there was apparently some difference between the action of the different rings, it was found that copper brushes running on copper were, in general, satisfactory. The brushes were in-clined against the rings, as in the actual machine, during this series of tests.

These tests were carried through with various numbers of brushes, etc. It was found that the number of brushes could be reduced to about one-third the full number, and still collect the total rated current, but that any great reduction from the full number of brushes made the operation of the rings and brushes more sensitive, and more attention was required to keep them in perfect condition. It was also found that any hardness or undue "springiness" in the brushes, or brush material, would tend to give increased wear. Brushes of very thin leaf copper, eventually gave best results. It was also shown by these tests that if a very good polish could be maintained on the rings, the rate of wear from day to day was practically unmeasurable on account of its smallness.

As a result of these ring tests, the rotor undergoing repair was equipped with outside copper wearing rings, spring supported. The material in the rings was about 92 per cent pure copper, 2 per cent zinc and 6 per cent tin.

The rotor was then installed in service and has been operating steadily for several years, with entire success. The other rotor, which had been operating while this rotor was being repaired, was then thoroughly examined after removal, to determine any possible defects. It was noted that the insulating tubes over the rotor conductors were badly cracked or buckled in a number of places. Upon removal of the rods or conductors it was found that the insulating tubes were stuck so tightly to the copper rods that they would be torn in pieces in trying to remove them. As it had been intended that these tubes should move freely on the rods or conductors, as previously described, it was evident that there was something radically wrong. The true cause of the trouble was then discovered. In first fitting this set of tubes over the rods, they had been too tight, and, in order to make them fit easily, the men who assembled the machine had reamed them on the inside to enlarge them, and, in doing so, had cut away the inner hard sheet of fish paper which had formed the lining, thus exposing a shellaced surface. As soon as heated, this shellac stuck the tube to the rod so that there could be no possible movement between the two. In consequence, when the rods expanded or contracted, the tubes moved backward and forward in the supporting holes, and wherever they stuck fast in the outer holes, something had to give, so that eventually the tubes buckled or cracked or pulled open. This was readily remedied by putting on new tubes properly constructed. As the rings on this rotor were in very good condition with but little worn away, the removable type of ring was not added, as this would require turning off a large amount of effective material on the existing rings and replacing it with new outer rings. It was decided that as there was several years' wear in the old rings, it would be of no material advantage to throw this away when it could be worn away in service, just as well as it could be turned off in a lathe. After the rings in this machine are worn down the permissible depth, they will be refilled by the addition of the removable type.

This unipolar generator has now been in service for quite a long period, with no difficulty whatever, and with an average ring wear of less than 0.001 in. per day, or less than $\frac{3}{8}$ in. per year. This may seem like an undue rate of wear; but in reality it is an extremely low rate, if the high peripheral speed, and the number of brushes, are considered. This machine operates day and night, seven days in the week, and practically continuously during the entire year. Taking the peripheral speed into account, the above rate of wear represents a total travel of each ring of about 3.6 million miles for each inch depth of wear, or about 150 times around the earth along a great circle. Considering that there are brushes bearing on each ring at intervals of about eight in., a wear of one in., for every 3.6 million miles traveled, does not seem unduly large. If, at the same time, it is considered that the brushes are collecting from 7500 to 10,000 amperes from each ring on a total ring surface of about $3\frac{1}{2}$ in. wide by 42 in. diameter, it is not surprising that there should be more or less "wear" due to the collection of this current. In fact, the current collected averages from 16 to 20 amperes per square inch of the total ring wearing surface. This may be compared with standard practice with large d-c. commutators, in which $1\frac{1}{2}$ to 2 amperes per square inch of commutator face is usual and 3 amperes is extreme.

On account of the final success of this machine, the story of its development is a more pleasant one to tell than is the case in some instances where entirely new types of apparatus are undertaken. It might be said, after reviewing the foregoing description, that many of the troubles encountered with this machine could have been foreseen; but such a statement would be open to question, for the engineers of the manufacturing company were in frequent session on all the various phases and difficulties which developed. The writer knows that in many cases, after any individual trouble was known, suggestion for remedies were not readily forthcoming. The writer does not know of any individual machine where more engineering and manufacturing skill was expended in endeavoring to bring about success, than was the case with this machine. As an example of engineering pertinacity, this machine is possibly without a rival. A mere telling of the story cannot give more than a slight idea of the actual fight to overcome the various difficulties encountered in the development of this machine.

The results obtained were valuable in many ways. Many data were obtained which have since been of great use, both from a theoretical as well as a practical standpoint, in other classes of apparatus. Certain fundamental conditions encountered in this machine have led to the study of other allied principles which point toward possibilities in other lines of endeavor. Therefore this machine, which was very costly in its development, may eventually pay for itself through improvements and developments in other lines of design.

The writer wishes to say a good word for the purchaser of this new apparatus. He was long-suffering, and was undoubtedly put to more or less trouble and inconvenience, but nevertheless he gave opportunity to correct difficulties. He recognized that the engineers were confronted with a new problem in this machine and he gave them an opportunity to carry it through to success. Apparatus of this type could only be developed to full success in commerical operation, as all the difficulties encountered would never have been found on shop test. Therefore, the attitude of the customer was of prime importance in the development of such a machine.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 25, 1912.

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ELECTROLYTIC CORROSION OF IRON BY DIRECT CURRENT IN STREET SOIL

BY ALBERT F. GANZ

The electrolytic corrosion of iron when exposed to an electric current leaving the iron in damp soil has already received a great deal of attention and is a matter of very great practical importance. Stray currents from direct-current electric railway systems employing the running tracks as return conductors frequently reach underground piping systems and cause corrosion by electrolysis. There has been some question as to whether or not the weight of iron oxidized or destroyed under the conditions existing on underground structures is equal to that calculated from Faraday's law, on the basis of 1.044 grams of iron destroyed by one ampere-hour, and whether various kinds of iron are corroded to the same extent with the same amount of current leaving the iron to pass to damp soil; and certain classes of iron have been claimed to resist electrolytic corrosion. Some have also believed that with very low current densities the amount of corrosion produced is less than the theoretical amount.

It has been shown that under some laboratory conditions iron assumes a passive state where the actual amount of corrosion produced is less than that calculated by Faraday's law, but it has not been shown that such conditions exist in the case of underground structures buried in street soils. The subject of electrolytic corrosion of iron is however so large and there are so many possible variations that a complete investigation covering every possible phase of the subject is impracticable in any one series of tests. In a recent paper*, Mr. J. L. R.

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*" Electrolytic Corrosion of Iron by Direct Current ", by J. L. R. Hayden, *Journal of the Franklin Institute*, October, 1911.

Hayden describes some laboratory experiments dealing admirably with the problem of the electrolytic corrosion of iron in various laboratory solutions when subjected to large current densities. The current densities used by Mr. Hayden ranged from 0.21 ampere per sq. ft. (2.25 amperes per sq. m.) to 3.35 amperes per sq. ft. (36 amperes per sq. m.). Mr. Hayden found that with a number of electrolytes, particularly with certain nitrates and with bichromates, much smaller amounts of corrosion were produced than the theoretical amount. In all of these cases, however, the greatest deviation from Faraday's law was found with the largest current densities. With chlorides and sulphates Mr. Hayden always found an amount of corrosion corresponding to the theoretical value. As Mr. Hayden has pointed out in the paper, his tests were made with laboratory solutions and not with street soils. The lowest current densities used by Mr. Hayden are also from 10 to 100 times greater than the densities with which currents are found in practise leaving underground structures. The tests described in Mr. Hayden's paper while exceedingly valuable do therefore not necessarily warrant any conclusion as to what will happen to pipes buried in street soils when subjected to stray electric currents.

The experiments described in the present paper were particularly designed to determine the relative rates of corrosion of various kinds of iron in two typical kinds of street soil, when subjected to such low current densities as are ordinarily found in practice on underground structures. Four sets of tests were made, each extending throughout 47 days to determine the rate of corrosion of commercial steel, commercial wrought iron, ingot iron, and cast iron, and to compare the actual amount of corrosion with that calculated by Faraday's law. It was attempted in these tests to approach practical conditions as nearly as possible. The tests were conducted in the electrical laboratory of Stevens Institute of Technology, and the detailed results are given in the following:

GENERAL DATA

Two kinds of soil were used in the tests, which were obtained from street excavations near gas mains in Long Island City. One of these excavations was chosen where the soil appeared to be largely light sand mixed with some clay, and the second was chosen where the soil was heavy and dark and appeared to be a mixture of clay and loam. Several barrels of soil from each excavation were obtained for these tests. To assure uniformity of soil conditions all of the soil of each kind was passed through a fine mesh sieve and then thoroughly mixed in a large wooden box before being used in the tests.

For the samples of iron, standard 1¼-in. (3.175-cm.) pipes were chosen such as are used ordinarily for service pipes, and these pipes were of commercial steel, commercial wrought iron and ingot iron, each test pipe being about 18 in. (45.72 cm.) long. The first two tests were conducted with these three kinds of iron pipe. For the third and fourth tests cast iron pipes of the same size were added.

The four sample pipes of each kind of iron used for the tests were placed in suitable test boxes. Each pipe was marked in the metal at one end with identifying numbers, and a hole was drilled and tapped at these ends for convenient electrical connection. Two pipes of each kind were placed in clay and loam soil, and two pipes of each kind in clay and sand soil; one set of pipes was subjected to damp soil only, and the other set of pipes was subjected to damp soil and to an externally applied electric current.

Before the tests were begun each pipe was thoroughly cleaned in a manner to be described in greater detail later, and was then weighed by two independent observers on a physical balance which responds to 10 milligrams. At the end of each test each pipe was similarly cleaned and again weighed on the same balance by two observers. From the difference in the weighings before and after the test the loss of weight was determined. The difference between the loss of weight of any one pipe subjected to damp soil with external electric current and the loss of weight of the corresponding pipe subjected to the action of the same kind of soil but without external electric current was taken as the loss of weight due to electrolysis.

In the case of the pipes which were subjected to external electric current, the strength of this current was determined in every case both by means of copper voltameters placed in series with the pipes, and by means of a current-time curve plotted from indicating meter readings taken every few days throughout the test. In general the results obtained from the voltameters and from the current-time curves agreed quite well, and the average of the two values was taken as the total quantity of electricity passed.

Four separate tests each of 47 days' duration were made.

The general results of these tests are given in Table I. In the first and second tests all of the pipes which were to be subjected to external electric current were connected in parallel to a constant-voltage supply, while in the third and fourth tests the pipes were connected in series, thus producing the same current flow from each pipe to the surrounding soil. During all tests the test boxes were kept in one of the laboratory rooms. The detailed conditions and arrangements of each test are given below.

Test No. 1. The pipes as received from the manufacturer were cleaned with kerosene and benzol and wire brushed to remove loose scale and rust. After having been thoroughly cleaned and dried they were placed in wooden test boxes. Four boxes were provided, each being approximately 12 in. by 12 in. by 12 in. (30. 48 cm. by 30.48 cm. by 30.48 cm.) inside dimensions, with three holes bored in each end through which the pipes projected. Three pipes, one of each kind of iron, were placed in each test box. A sheet of copper placed at the bottom and a piece of copper wire gauze placed on top served as ground plates. Two boxes, containing clay and sand soil with three test pipes in each box, and two boxes containing clay and loam soil with three test pipes in each box, were set up with ground plates as above described. A storage battery, having a voltage of approximately 14 volts, was connected with its positive terminal to the pipes in two boxes one with each kind of soil, and its negative terminal to the ground plates. In circuit with each of these pipes was placed a suitable copper voltameter. No external electromotive force was applied between pipes and ground plates in the remaining two boxes. During the test, 250 cu. cm. of hydrant water was added to each test box approximately every third day in order to keep the soil damp. In the case of the pipes subjected to external electricity, the current delivered to each pipe was measured practically every day by means of an ammeter inserted temporarily, and the voltage between pipes and ground plates was also measured. After the test had been continued in this way for 47 days the test pipes were removed from their boxes, washed in hot water to remove adhering soil, soaked in kerosene to soften the rust, wire brushed until clean, then washed in benzol, dried and weighed as before.

Test No. 2. For test No. 2 the pipes were taken directly at the end of Test No. 1 and replaced in their test boxes. The same boxes and the same soil and ground plates were used as in test No. 1. All conditions of test No. 2 were identical with those of test No. 1 except that a caustic potash battery was used to maintain the pipes 0.7 volt positive to the ground plates and 200 cu. cm. of hydrant water was added to each box practically every day, thus maintaining the soil in a damper condition than in test No. 1. At the end of 47 days the pipes were again removed, and cleaned and weighed in the same manner as after test. No. 1.

Test No. 3. For test No. 3 the same pipes were used as received from test No. 2, with the addition of four cast iron pipes, which before being subjected to test were also cleaned with kerosene and benzol and then dried and weighed. In this test it was desired to subject each pipe to the same current instead of to the same voltage as in tests No. 1 and No. 2. For this reason 16 test boxes were constructed each approximately 16 in. by 6 in. by 6 in. (40.6 cm. by 15 cm. by 15 cm.) internal dimensions, with one hole in each end through which the pipe projected, thus exposing 16 in. (40.6 cm.) of each test pipe to soil. The ground plate in each test box was placed at the two sides and the bottom and top of each box, thus completely surrounding the test pipe, the lower portion of the ground plate consisting of copper sheeting and the upper portion of copper wire gauze. The soil was obtained from the test boxes used in tests No. 1 and No. 2, each kind of soil being mixed thoroughly together with some additional soil of the same kind left over from the original shipment. Eight of the new test boxes were filled with clay and sand soil and eight with clay and loam soil, and one pipe was placed in each test box. Four boxes containing clay and sand soil, each containing a different kind of iron pipe, and four boxes containing clay and loam soil, each containing a different kind of iron pipe were connected electrically in series—that is, the pipe in one box was connected to the ground plate of the next box. A potential difference of about 125 volts was maintained across the eight boxes by means of a storage battery. In this way the same current was made to flow from each pipe to the surrounding soil. In series with the circuit were placed two copper voltameters. The remaining eight boxes, four with each kind of soil, were left without electrical connections so that the pipes in them were subjected to damp soil only. During the test approximately 100 cu. cm. of hydrant water was added practically every day to each box, and the current in the circuit and the potential difference between pipe and ground plate in each box was measured every few days. At the end of 47 days each pipe was removed from its box, washed with hot water to remove the adhering soil, soaked in ammonium citrate to loosen and remove the rust, wire brushed, then washed in naptha, dried and weighed. Ammonium citrate was used as it had been found by trial that this would more quickly and more effectively loosen rust than would kerosene or benzol.

Test No. 4. In order to eliminate all possible effects of previous corrosion, scale, etc., each test pipe was turned down in a lathe to bright metal, then cleaned with naptha, soaked in ammonium citrate, rinsed in water and naptha, then dried and weighed. The pipes were then replaced in their boxes and the test run practically in the same manner as test No. 3, except that 150 cu.cm. of hydrant water was added to each test box each day, thus maintaining the soil damper than in test No. 3, and that a recording milliammeter was kept in circuit. At the end of 47 days each pipe was removed and subjected to exactly the same cleaning processes as at the end of test No. 3. They were then dried and weighed as before.

RESULTS OF PHYSICAL EXAMINATION OF PIPES AFTER TESTS

The pipes which had been subjected to damp soil only showed slight surface corrosion but no pitting after test No. 1 and test No. 2, and some slight pitting after test No. 3, but in no case was this pitting comparable in severity with that produced where an external electric current had been applied. After test No. 1 the coating of scale originally on the pipes was found practically intact, but it was found partly removed after test No. 2 and had almost completely disappeared after test No. 3, the scale then remaining being in well defined patches which showed little corrosion. After test No. 4 where all scale had previously been removed the corrosion was extremely uniform without the slightest evidence of pitting. It will be noted from Table I, in the column marked *B*, that these pipes in general showed an increasing loss in weight in the successive tests, with the exception of test No. 4, where the loss in weight was in general slightly less than that in test No. 3.

Pipes subjected to damp soil plus applied external electric current showed some evidence of pitting after the first test, the pits becoming more pronounced after tests No. 2 and No. 3. After test No. 4 the pitting was found quite as severe as after test No. 3. It

will be noticed also from the last column in Table I that the value of the ratio of the actual loss from electrolysis to the theoretical loss decreases in general in the successive tests, that is‘ as the scale is removed. Hence it would appear that with the exception of cast iron the scale does not protect pipes from electrolysis and may even aggravate it. It is also evident that localized corrosion resulting in pitting occurs even when all scale has been removed and a uniform metallic surface is exposed to the soil. In the case of cast iron the iron is oxidized by electrolysis but remains in place as a graphitic mass having little mechanical strength but retaining the surface in its original condition without exposing pits. This graphitic material is quite soft and can be easily dug out with a knife or other suitable tool.

DISCUSSION OF RESULTS

The current-time curves for each test show a rapid falling off of the current during the first few days. As an example of this the following values of current are given from test No. 3:

At beginning of test	0.100	ampere.
At end of 1st day	0.050	"
" " " 2nd day	0.0298	"
" " " 5th day	0.0125	"
" " " 12th day	0.0072	"
" " " 19th day	0.0062	"
" " " 29th day	0.0050	"
" " " 47th day	0.0033	"

This indicates that the resistance increases very rapidly at first and then increases only very slowly. This increase in resistance was found to take place at the surface of the pipe or in the layer of soil immediately surrounding the pipe. This was determined by means of a separate test, in which, after the resistance had increased, the pipe was removed, wiped off with waste, and immediately replaced, when it was found that the resistance was again as low as at the beginning of the test.

The detailed results of the tests and of the calculations made from these results are given in Table I. In the fourth column of this table the average voltage between each test pipe and the ground plate is given in volts. In the first test each pipe was maintained at a constant positive potential of 14 volts, and the current produced by this voltage varied with each pipe, being determined by the accidental resistance of soil and of the surface contacts in each case. In the second test the pipes were maintained at a constant voltage of 0.69 volt, and the current from each pipe varied as before. In test No. 3 the pipes were all connected in series so that the current leaving each pipe was the same, but the voltage between each pipe and the ground plate now varied. It will be noted that this voltage ranged from 24.5 to 37.3 volts in the clay and sand soil, while in the clay and loam soil it was less than one volt. In test No. 4 the pipes were again connected in series, and the voltage in the clay and sand soil ranged from 15.4 to 26.3 volts, while in the clay and loam soil it ranged from 8.53 to 17.0 volts. While the applied voltage in tests No. 3 and No. 4 was the same, it will be noted that the average current in test No. 4 was over three times as large as in test No. 3.

Since the same soils were used in tests No. 3 and No. 4, this difference in current and in relative voltages, indicating changes in resistance, may be due to the fact that for test No. 4 the pipes were turned down to a smooth surface whereby better and more uniform contact was secured between pipes and soil.

The actual loss of weight of the pipes in the tests as determined from the weighings made before and after the tests, is given in columns *A* and *B* of Table 1. The difference between the loss of weight of any pipe subjected to damp soil with applied electric current and the loss of weight of the corresponding pipe subjected only to damp soil is taken as the loss of weight due to electrolysis and is given in column *C*. The theoretical loss from electrolysis as calculated from the ampere-hours which passed from each pipe to the surrounding soil, and from the electrochemical equivalent of iron, namely 1.044 grams per ampere-hour, is given in column *D*. The actual total loss (column *A*) divided by the theoretical loss from electrolysis (column *D*) is given in the next to the last column marked $\frac{A}{D}$, and the approximate actual loss from electrolysis (column *C*) divided by the theoretical loss from electrolysis (column *D*) is given in the last column marked $\frac{C}{D}$.

It will be noted that in every case the actual total loss divided by the theoretical loss from electrolysis is greater than unity, and that the approximate actual loss from electrolysis divided by the theoretical loss from electrolysis, as given in the last column of Table I, is also greater than unity in every case but three, in which cases these values are 0.96, 0.95, and 0.88. As already stated, in the case of the cast iron pipes there is left as the result of electrolysis a soft graphitic material which is difficult to remove. The one low value of 0.88, obtained for cast iron in test No. 3, is therefore probably accounted for by the fact that this graphitic material had not all been removed.

An examination of the last column of the table shows that the actual loss from electrolysis divided by the theoretical loss was much larger in the first test than in the last test, particularly in the case of clay and sand soil. In one of these cases in the first test the actual loss of weight from electrolysis divided by the theoretical loss was as high as 5.3. This may be partly due to some scale having been loosened by corrosion of the metal and afterward brushed off in the cleaning of the pipes. It may be remarked, however, that after test No. 3 a physical examination of the pipes showed that those which had been subjected to the action of damp soil only appeared to have lost nearly as much of the original scale as those acted upon by electric current. It, therefore, does not seem likely that the large values of the ratios above mentioned are entirely due to loss of scale, but rather indicates that a great deal more than the theoretical amount of iron was lost by electrolysis.

It will be noted that the loss of weight by electrolysis appears to be absolutely independent of the applied voltage, except in so far as the voltage determines the amount of current produced, 0.7 volt being quite as effective in producing corrosion as 30 volts.

No chemical analyses of the soils used were made, except that a sample from each kind of soil was tested for chlorides and showed the presence of these salts.

CONCLUSIONS

The duration of these tests were not sufficiently long to warrant positive conclusions to be drawn regarding the relative corrosion of the four kinds of iron tested, when subjected only to the action of damp soil. The following conclusions appear however to be warranted:

The corrosion of iron by electrolysis in the two kinds of street soil tested is independent of the value of the applied voltage, except in so far as this determines the amount of current produced, and less than one volt can produce corrosion by electrolysis.

For the two kinds of street soils tested, and with current densities ranging from 1.7 milliamperes per sq. ft. (18.3 milliamperes per sq. m.) to 54 milliamperes per sq.. ft. (581 milliamperes per sq. m.), the loss of weight of iron by electrolysis is at least equal to that calculated by Faraday's law, and is in general greater than the theoretical loss. In all cases electrolysis tends to cause localized corrosion and decided pitting. Surface scale appears to accelerate corrosion from electrolysis with all irons except cast iron; this was especially pronounced in the case of the steel pipes tested. When the surface scale was removed there was practically no difference in the amount of corrosion produced by a given current leaving iron for damp soil between commercial steel, commercial wrought iron, ingot iron and cast iron.

It should be pointed out that the electrical resistance of cast iron is about ten times as great as that of wrought iron, steel, or ingot iron, and the usual lead joints in cast iron pipes also have a resistance which is many times greater than the screw coupling joints usual with wrought iron and steel pipes. For these reasons a given voltage drop through ground will cause a much smaller current to flow on a cast iron pipe than on a wrought iron or a steel pipe, thus practically making cast iron pipes much less subject to electrolysis than wrought iron or steel pipes. It must also be noted that when a cast iron pipe is corroded by electrolysis, the iron is oxidized but remains in place as a graphitic mass having little mechanical strength, but possessing the ability to maintain the pipe gas-tight and sometimes even water-tight for considerable periods, while with wrought iron or steel pipes this does not occur so that holes and consequent leaks are more quickly produced. Frequently where cast iron pipes appear to be immune from electrolysis because no evidences of leakage have developed, an examination of the pipes would reveal that a great deal of corrosion has actually taken place and that the pipes have been very greatly weakened.

The tests described in this paper are by no means considered complete. There are in fact so many possible variables, such as different kinds of soil, different degrees of wetting the soil, different kinds of iron, different voltages, different current densities, etc., that it would be extremely laborious to make a complete set of tests. The writer expects however to continue the experiments along the line outlined in this paper and hopes that the discussion will bring out suggestions which will serve to make the next series of tests more valuable.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 25, 1912.

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THE CONVECTION AND CONDUCTION OF HEAT IN GASES

BY IRVING LANGMUIR

In a previous* paper the author has shown that the "convection" of heat from hot wires in a gas consists essentially of *conduction* through a film of relatively stationary gas around the wire. From this theory the following method was derived for calculating the power necessary to maintain a wire at any given temperature.

The loss of energy from a wire is made up of two parts, radiation and convection. Let us call this convection **W**, expressed in watts per cm. of length of the wire. Then **W** is equal to the product of two factors, thus

$$\mathbf{W} = \mathbf{s}\,(\varphi_2 - \varphi_1) \tag{1}$$

The first factor, **s**, is called the "shape factor" and depends only on the ratio of the diameter of the wire, *a*, to the diameter, *b*, of the conducting film around the wire. This relation is

$$\mathbf{s} = \frac{2\pi}{ln\,\frac{b}{a}} \tag{2}$$

But **s** can be calculated directly without a knowledge of the film diameter *b* by solving the following equation

$$\frac{a}{B} = \frac{\mathbf{s}}{\pi}\,\epsilon^{-\frac{2\pi}{\mathbf{s}}} \tag{3}$$

**Physical Review*, May, 1912.

Here a is the diameter of the wire and B is the thickness of the conducting film for the case of convection from a plane surface.

The second factor in (**1**) is $\varphi_2 - \varphi_1$ where φ depends only on the heat conductivity of the air, **k**, (in watts per cm.) and the temperature of the wire and of the atmosphere. Thus

$$\varphi_1 = \int_0^{T_1} \mathbf{k}\, d\, T \qquad \varphi_2 = \int_0^{T_2} \mathbf{k}\, d\, T \qquad (4)$$

Here T_1 is the temperature of the atmosphere and T_2 the temperature of the wire.

Both of the operations involved in (**3**) and (**4**) are made very easy by plotting two curves, one giving the relation of **s** to $\frac{a}{B}$ and the other relation of φ to T. Data for the plotting of these curves is given in the paper referred to above.

Thus the only data necessary for a calculation of the free convection from a horizontal wire (of given diameter and temperature) in a gas of known temperature is

1. The heat conductivity of the gas as a function of the temperature.
2. The value of B.

It was shown experimentally that for air at room temperature and atmospheric pressure, B is equal to 0.43 cm. and is independent of the temperature, T_2, of the wire, even when this varies from slightly above room temperature up to the melting-point of platinum.

It was shown that with five different sizes of wire ranging from $a = 0.0038$ cm. up to $a = 0.0500$ cm., the energy **W** calculated from (**1**) and (**3**) agreed excellently with experiments. This is equivalent to saying that the experimentally determined values of B were found to be independent of the diameter of the wire used in the experiment.

The theory would indicate that B should vary with

1. The nature of the gas.
2. The pressure of the gas.
3. The temperature of the gas.
4. In the case of forced convection, B should vary with the wind velocity.

The present paper will deal with the effect of the second and fourth of the above factors on the thickness of the conducting film.

Kennelly in his excellent paper on the "Convection of Heat from Small Copper Wires"* has investigated the effect of the following factors

1. Diameter of wire. Varied from 0.011 to 0.069 cm.
2. Temperature of wire. With the free convection tests this varied from 40 deg. cent. to 200 deg. cent., but with the forced convection temperatures as high as 325 deg. cent. were used.
3. Pressure of air. Varied from 12 up to 190 cm. of mercury.
4. Wind velocity. Varied from 0 up to 2000 cm. per second.

He did not investigate other gases than air, nor try air at other than room temperature.

Kennelly derives certain purely empirical formulas to express his results. Combining them, he gives for **W**, the watts lost by free convection per cm. of length,

$$\mathbf{W} = (0.0004 + 0.0064a)\,(T_2 - T_1)P^{0.9\sqrt[3]{a}} \qquad (5)$$

where a is the diameter of the wire

P is the pressure of air in atmospheres.

For forced convection he finds

$$\mathbf{W} = (0.00003 + 0.00580a)\,(T_2 - T_1)\,\sqrt{v + 25} \qquad (6)$$

where v is the wind velocity in cm. per sec.

Thus to express his results on free convection he needs to use four empirical constants and to express the results on forced convection three more are needed. But even with all these empirical constants, the calculated values do not agree very well with the experiments. The average difference between the calculated and observed values of **W** for experiments on free convection is approximately 12 per cent, while in one experiment the differences are as high as 30 per cent.

Let us now analyze Kennelly's data more closely and apply to it the theory of the conducting film, thus deriving the relation between the film thickness B and the pressure and wind velocity of the air.

KENNELLY'S DATA ON FREE CONVECTION

The experimental results on free convection are given by Kennelly in ten logarithmic plots, the coordinates being pressures and current through the wire. He does not give the resistances of the wires at the temperature of the experiment, but does give the resistance of each of the wires at 0 deg. cent. and gives the elevation of temperature above room temperature, calculated from the resistance. He used for this calculation the formula

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* TRANSACTIONS A. I. E. E. Vol. XXVIII, 1909, p. 363.

$$R_T = R_0\,(1 + 0.0042\ T_c)$$

where R_T is the resistance at the temperature T_c (in deg. cent.) and R_0 is the resistance at 0 deg. cent. He did not measure the temperature coefficient of the wire used, but assumed that the wires were of pure copper and that the temperature coefficient was that given above. He does not state the room temperature during the experiments, so I have assumed it to be 20 deg. cent., and have thus calculated the resistance of the wires from his data on the temperature elevation above room temperature and from the given temperature coefficient. By taking the product of the resistance per cm. and the square of the current, I have then calculated **W** the watts per cm. supplied to the wire. This is given in the following tables as " **W** obs. "

Kennelly is very uncertain as to how large the correction for radiation should be, and finally assumes that the copper wires radiate 94 per cent as much as a black body at the same temperature. This correction amounts to about 2 per cent for the smallest wire and becomes about 8 per cent of the total energy for the largest wire. But there is ample data in the literature to show that radiation from a bright metallic surface is very much less than 94 per cent of that from a black body. A great deal of recent work has shown conclusively that the reflectivity, **r**, of any metal for heat rays of wave length longer than $\lambda = 6\ \mu$ is accurately given by Hagen and Ruben's formula*

$$1 - \mathbf{r} = 0.365\sqrt{\frac{\sigma}{\lambda}}$$

where σ = specific electrical resistance of the metal
λ = wave length of the light.

By Wien's displacement law the wave length λ_M of the light of greatest intensity in the spectrum from a black body at temperature T is

$$\lambda_M = \frac{0.29}{T}\ \text{cm.}$$

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[*] *Ann Phys.* 8. 1, 1902.

Therefore for radiation of heat at room temperature, about 300 deg. K.* the wave length would be about 0.0009 cm. or 9μ

Now for copper $\sigma = 1.7 \times 10^{-6}$
and for platinum $\sigma = 11.0 \times 10^{-6}$
Whence approximately
for copper $1 - r = 0.0158$
and for platinum $1 - r = 0.040$.

That is, at room temperature copper would radiate 1.6 per cent and platinum about 4.0 per cent, as much as a black body. This result for platinum is in fairly good agreement with Lummer and Kurlbaum's† measurements on the radiation from platinum. In any case, it is a very safe conclusion that the radiation from bright copper surfaces is much less than 50 per cent and therefore that it would have been better if Kennelly had neglected radiation, instead of correcting for it.

Therefore, in using Kennelly's data, we shall use the total watts as observed, rather than the values he gives for convection. At the relatively low temperatures at which his experiments were carried on, radiation probably does not exceed 1 per cent of the total losses.

In the above table the first column gives the diameter of the wire in cm. The second column gives the temperature elevation above room temperature given by Kennelly and calculated by him from the resistance. In the second column there is also given $\varphi_2 - \varphi_1$, taken from a very large scale curve prepared from the data given in the previous paper. T_1 is assumed to be 293 deg. K. The third column gives the resistance per cm. of length of the wire, calculated from the resistance at 0 deg. cent. given by Kennelly and from the temperature coefficient 0.0042 used by him in calculating $T_2 - T_1$. Hence any error in assuming a wrong value for this temperature coefficient is eliminated.

In the fourth and fifth columns is the data obtained directly from the plots given by Kennelly. Smooth curves were drawn through the points given by Kennelly without any reference to the straight lines that he uses to express his results. The ordinates of these curves at three or four well-distributed pressures were read off and are given in column V. The pressures are given in megabars (*i.e.*, 0.987 atmospheric pressure). In column VI is given the watts per cm. obtained simply by multiplying the figures in columns III by the square of the

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*Degrees Kelvin (Absolute temperature).

†*Verh. Phys. Ges.*, Berlin, 17, 106, 1898.

TABLE I
KENNELLY'S EXPERIMENTS ON FREE CONVECTION

I	II	III	IV	V	VI	VII	VIII	IX	X
Diam. of Wire cm.	T_2-T_1 and $\phi_1-\phi_2$	Resistance $\frac{\text{Ohms}}{\text{cm.}}$	Pressure P megabars	Amps.	**W** obs.	**W** calc.	B obs. cm.	B_1 calc. cm.	x
0.0114	165.0	0.0273	0.325	1.72	0.0810	0.0811	1.04	0.46	−0.73
			1.00	1.89	0.0978	0.0980	0.44		
			1.70	1.98	0.1072	0.1017	0.31		
	0.0497		2.25	2.02	0.1114	0.1142	0.27		
0.0114	95.9	0.0228	0.35	1.47	0.0494	0.0439	0.54	0.49	−0.94?
			1.00	1.50	0.0513	0.0524	0.49		
			1.50	1.56	0.0556	0.0569	0.35		
	0.0266		2.25	1.65	0.0621	0.0612	0.23		
0.0114	59.6	0.0205	0.33	1.13	0.0261	0.0260	0.95	0.46	−0.80
			1.00	1.21	0.0300	0.0312	0.50		
			1.50	1.27	0.0330	0.0337	0.35		
	0.0158		2.25	1.36	0.0379	0.0364	0.21		
0.0262	58.8	0.00392	0.40	2.80	0.0308	0.0320	0.99	0.45	−0.84
			1.00	3.11	0.0380	0.0381	0.44		
	0.0156		2.00	3.41	0.0455	0.0446	0.24		
0.0262	46.4	0.00377	0.30	2.34	0.0206	0.0235	1.92	0.59	−0.95
			0.60	2.55	0.0245	0.0268	0.91		
			1.00	2.70	0.0275	0.0296	0.56		
	0.0121		2.00	2.95	0.0328	0.0346	0.31		
0.0262	37.8	0.00367	0.70	2.18	0.0175	0.0220	1.47	0.96?	−1.28?
			1.25	2.38	0.0208	0.0249	0.73		
	0.0097		2.00	2.59	0.0246	0.0277	0.39		
0.0262	15.1	0.00326	0.30	1.53	0.0076	0.0074	0.92	0.35	−0.86
			0.60	1.65	0.0089	0.0084	0.51		
			1.00	1.73	0.0098	0.0093	0.36		
	0.0038		2.00	1.95	0.0124	0.0109	0.17		
0.0691	179.8	0.000770	0.33	14.3	0.1575	0.139	0.68	0.32	−0.77
			1.00	16.5	0.2100	0.181	0.34		
			1.50	17.5	0.236	0.204	0.22		
	0.0550		2.25	18.4	0.261	0.227	0.17		
0.0691	77.2	0.000591	0.37	10.0	0.0591	0.0545	0.71	0.34	−0.75
			1.00	11.4	0.0770	0.0693	0.33		
			1.50	12.2	0.0880	0.0777	0.23		
	0.0210		2.25	12.9	0.0984	0.0868	0.17		
0.0691	18.3	0.000489	0.50	5.3	0.0138	0.0128	0.57	0.38	−0.66
			1.00	5.7	0.0159	0.0152	0.38		
	0.0046		2.00	6.25	0.0192	0.0185	0.23		

figures in column V. For the reasons already given, no correction for radiation was made.

In column VIII is given the of value B calculated as follows:

The value of **s** is found (equation **1**) by dividing **W** (column VI by $(\varphi_2 - \varphi_1)$ (column II). From a curve of equation **(3)** drawn from data in the previous paper, the value of $\frac{a}{B}$ corresponding to the given value of **s** was found. This quantity divided into, a, the diameter of the wire (column I) gives B (column VIII).

It was thought that B would be found to vary inversely proportional to the pressure. In the previous paper the hypothesis was advanced that B would vary proportionally to the viscosity and inversely proportional to the density of the gas. This, however, was not very well borne out by experiments in hydrogen and mercury vapor. According to this hypothesis, B should vary inversely with the first power of the pressure, for the viscosity is independent of the pressure.

It will be observed, however, that the product obtained by multiplying together the values in columns IV and VIII shows a very distinct tendency to increase with the pressure. The quantity B was therefore plotted on logarithmic paper, as a function of P, with the result that the points were found in nearly every case to lie in straight lines. For each of the experiments with a wire at any given temperature, a straight line was drawn in this way. The ordinate of these lines for a pressure of 1 megabar was read off and is given in the above table, in column IX. The slope of the straight line, n, is given in column X. The fact that the logarithmic plots gave practically straight lines means that B varies with the nth power of the pressure. The values of n in the different experiments do not show any distinct tendency to vary either with a or with the temperature. By a careful study of the curves, the most probable value of n was thought to be about -0.75. It is true that the average of the values of n is numerically larger than 0.75, but the sets of experiments which seem to be most free from experimental error give values close to this.

To test the accuracy of this conclusion, the figures in column VII were calculated, based on the following assumptions

1. The thickness of the plane film, B, for air at room temperature and 760 mm. pressure, is 0.43 cm. This is the value found from the experiments on platinum wires described in the previous paper.

2. That B varies inversely as the 0.75th power of the pressure (P). At a pressure of 1 megabar B would be 0.436 cm.

By aid of the above assumptions, the values of B were calculated, and from these the ratios $\frac{a}{B}$; then **s** was found by the plot of (**3**), and this was multiplied by $(\varphi_2 - \varphi_1)$ (column II), to obtain "**W** calc." in column VII.

The agreement between the calculated convection and that observed by Kennelly is strikingly good. The only serious discrepancy between the two occurs with the largest wire at the highest temperature. This discrepancy may perhaps largely be accounted for by radiation. A "black" wire of 0.069 cm. diameter at a temperature of 179 deg. above room temperature would radiate about 0.050 watts per cm. A polished copper wire would radiate only about 0.001 watt, but if the surface is slightly oxidized or tarnished, it might easily radiate much more. The difference between the calculated and observed watts is only about 0.025, so that if the wire should radiate 50 per cent as much as a black body this difference would be accounted for.

It is interesting to note that with only two empirically determined constants, the equation (**1**) allows a much closer calculation of **W** than did Kennelly's equation with its four empirical constants.

KENNELLY'S DATA ON FORCED CONVECTION

By forced convection Kennelly means the convection of heat from a wire which is moving rapidly relatively to the surrounding air.

Kennelly's results on forced convection are given in two logarithmic plots. In one the amperes are plotted against the wind velocity and in the other the watts per cm. of length are plotted against wind velocity. He has corrected the watts as before for radiation, but in this case the loss by convection is so great that the radiation correction is small enough to be quite negligible. Therefore I have taken Kennelly's results for the watts directly and have not calculated them from the amperes, as in the case of free convection. The following table gives a summary of Kennelly's experimental data

The third and fourth columns were obtained, as before, by drawing smooth curves as nearly as possible through the points given by Kennelly, without any reference to the straight lines

TABLE II
KENNELLY'S EXPERIMENTS ON FORCED CONVECTION

I	II	III	IV	V	VI	VII	VIII
Diameter of wire cm.	T_2-T_1 and $\phi_2-\phi_1$.	Wind velocity $\frac{\text{cm.}}{\text{sec.}}$	W obs. $\frac{\text{watts.}}{\text{cm.}}$	W calc. $\frac{\text{watts.}}{\text{cm.}}$	B $\times 10^3$ cm.	B_{900} obs. $\times 10^3$	B_{900} calc. $\times 10^3$
0.0101	106	520	0.220	0.222	10.0	6.55	6.56
		900	0.280	0.281	6.55		
	0.0298	1800	0.388	0.390	3.90		
0.0101	179	400	0.320	0.350	16.0	8.1	7.29
		900	0.466	0.485	7.8		
	0.0550	1800	0.650	0.671	4.65		
0.0101	252	400	0.486	0.502	15.9	8.4	8.02
		900	0.690	0.693	8.13		
	0.0830	1800	0.960	0.950	4.75		
0.0159	117	330	0.250	0.262	15.5	7.1	6.68
		900	0.408	0.415	6.89		
	0.0335	1800	0.590	0.596	4.05		
0.0159	211	330	0.490	0.487	16.2	7.6	7.60
		900	0.760	0.757	7.68		
	0.0670	1800	1.100	1.079	4.45		
0.0159	305	330	0.720	0.735	18.5	8.5	8.55
		900	1.130	1.122	8.46		
	0.1060	1800	1.600	1.590	4.99		
0.0204	51	800	0.217	0.200	5.81	5.9	6.00
		1300	0.252	0.260	4.75		
	0.0134	1800	0.314	0.315	3.60		
0.0204	128	210	0.297	0.274	17.6	6.3	6.78
		400	0.380	0.362	11.45		
		900	0.570	0.536	6.25		
	0.0370	1800	0.810	0.788	3.89		
0.0204	206	210	0.475	0.453	20.8	7.2	7.56
		400	0.620	0.596	13.0		
		900	0.910	0.896	7.16		
	0.0650	1800	1.280	1.280	4.48		
0.0204	283	210	0.660	0.642	23.4	7.9	8.33
		400	0.880	0.835	14.0		
		900	1.260	1.215	7.96		
	0.0965	1800	1.780	1.758	4.87		

plotted by him. The figures in columns III and IV of the table represent simply three or four well distributed points taken from these curves.

The thickness, B, of the plane film (column VI) was calculated similarly to B in Table I.

It is seen that B decreases as the wind velocity increases. To study the law with which this varies, B was plotted against V on logarithmic paper and a series of parallel straight lines was obtained. The slope of these lines was -0.75. In other words, B varies inversely as the 0.75 power of the wind velocity.

The ordinates of these straight lines corresponding to the abscissa $V = 900$ are given in column VII.

It is seen that B_{900} increases distinctly as the temperature difference $T_2 - T_1$ increases. But it apparently does not perceptibly depend on the diameter of the wire. By plotting B_{900} against $T_2 - T_1$ it was found that the following equation gives a fairly good approximation of B_{900}

$$B_{900} = 0.0055 + 0.000010\,(T_2 - T_1) \tag{7}$$

Column VIII gives the values of B_{900} calculated from this formula.

In the case of free convection, it will be remembered that B was found to be independent of the temperature T_2 of the wire, even up to the melting-point of platinum. The reason that the temperature enters here is probably that with forced convection the viscosity of the inner and hotter portions of the gas film is a factor determining the thickness of the film, whereas in the case of free convection only the viscosity of the outer portions is of importance. Between the temperatures 300 deg. and 600 deg. K, the temperature coefficient of the viscosity, $\mathfrak{h}$, is 0.00219, whereas the temperature coefficient of B_{900} is $0.00001 \div 0.0055 = 0.00180$, or about 83 per cent of that of the viscosity. In other words, for forced convection B is approximately proportional to the viscosity of the gas at a point $\frac{1}{6}$ of the way from the surface of the wire to the outer edge of the film.

The values of **W** given in column V were calculated by first determining B for the wind velocity given in column III by means of the relation

$$\frac{B}{B_{900}} = \left(\frac{900}{V}\right)^{0.75} \tag{8}$$

From this value of B, **W** was calculated in the usual way.

If we assume that equation (8) holds down to very low velocities and substitute for B the value 0.43 cm. found for free convection and for B_{900} the value from (7), we find for the velocity V_0 which exists in free convection

$$V_0 = 2.7\,[1 + 0.0024\,(T_2 - T_1)] \text{ cm. per sec.}$$

Kennelly had concluded from his observations that the energy loss from the wires varied directly as the square root of the wind velocity. According to the present theory this could only occur for wires of a certain size.

In case the diameter of the wire is large compared to the film thickness B, we should expect the energy to be inversely proportional to B; that is, directly proportional to the 0.75 power of the wind velocity. For wires of smaller size the energy would vary less rapidly with the wind velocity, so that for wires of a certain size it would vary approximately with the square root of the wind velocity.

Kennelly's experiments cover only such a narrow range of sizes of wire that his data furnish no way of testing this deduction from the theory. But it should be pointed out that many other observers have concluded in experiments on the rate of solutions of solids in liquids and other similar phenomena, that the thickness of the diffusion film varies inversely as the 0.70 or 0.75 power of the rate of stirring. As far as I know however, the case where the size of the wire is small compared to thickness of the film has not been handled.

SUMMARY

Kennelly's data on the "Convection of Heat from Small Copper Wires" afford strong proof of the reliability and usefulness of the author's theory of convection. According to this theory, "convection" consists essentially in conduction of heat through a film of gas of definite thickness, in which the heat carried by motion of the gas is negligible compared to that carried by conduction, and outside of which the temperature is maintained uniform because of convection currents. The thickness of the film of gas is related in a sample way to the diameter of the wire, so that from the experiments the thickness B, which the film would have in case of a plane surface, can be readily calculated.

Previous results of the author have shown that

1. The quantity B, for quiet air at room temperature and one atmosphere pressure, is equal to 0.43 cm.

2. *B* is independent of the temperature of the wire from room temperature up to the melting-point of platinum, 1750 deg. cent.

3. The values of *B* obtained from experiments on wires of different sizes are found to be the same.

In the present paper it is shown that Kennelly's results confirm the above conclusions and furthermore lead to the following new conclusions:

4. The film thickness (for plane surface) *B* varies inversely as the 0.75th power of the pressure of the gas.

5. The value of *B* varies inversely as the 0.75th power of the wind velocity.

6. Although for free convection, *B* was found independent of the temperature of the wire, it is found that for forced convection *B* increases slightly with the temperature. See equation (**7**).

7. For forced convection, however, the value of *B* is found independent of the diameter of the wire, just as in the case of free convection.

8. Radiation from small metallic wires is practically negligible compared to convection, up to temperatures of several hundred degrees.

In a series of subsequent papers it will be shown that

1. The value of *B* increases approximately proportional to the absolute temperature of the atmosphere surrounding the wire, even when the latter varies from —190 deg. to 300 deg. cent.

2. The value of *B* found from actual experiments on the convection from plane surfaces agrees excellently with the value found from small wires. In the case of plane surfaces, however, the radiation loss is usually much greater than that by convection, so that a careful study of the radiating properties of the surface has to be made. It will be shown that the convection losses from cylinders of any size, as well as from plane surfaces, can be accurately calculated from the formulas given in this paper.

3. In the case of convection between two surfaces (for example, between two concentric cylinders or two boxes one in the other), the theory of the conducting film proves extremely useful and makes it possible to calculate nearly all simple cases of heat convection with reasonable accuracy.

These papers will also contain evidence of many kinds which clearly indicate the significance of the conducting film.

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(*Subject to final revision for the Transactions.*)

THE VIBRATIONS OF TELEPHONE DIAPHRAGMS

BY CHARLES F. MEYER AND J. B. WHITEHEAD

HISTORY

Investigations of the vibrations of telephone diaphragms have been published by Rayleigh,[1] Wien,[2] Kempf-Hartmann,[3] Taylor[4], Gati[5] and others. Rayleigh and Wien measured the value of the simple harmonic current which would just produce an audible tone in the receiver at different frequencies. They found that at certain frequencies the current required was a minimum, and Wien concluded that these minima showed the existence of natural vibrations of the diaphragm, but realized that the variation in sensibility of the ear with pitch played possibly a larger part in the difference of current required at different frequencies than the natural vibrations themselves.

Kempf-Hartmann fastened a mirror on the diaphragm of a receiver and photographed on a moving film the oscillations of a spot of light reflected from the mirror. By passing direct current interrupted about 100 times per second through the telephone he was able to photograph the natural oscillations of the diaphragm which were produced at each make and break, and showed also that when the diaphragm had been given an impulse its reaction could be detected after about 1/2000 of a second.

Taylor has plotted curves showing the connection between the least current producing an audible tone and the frequency, his work being similar to that of Rayleigh and Wien. He noticed that as the alternating current generator from which he obtained his current accelerated or slowed down there were certain frequencies at which the sound from the receiver was very much increased, and he plotted rough curves showing this.

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[1] Rayleigh. "Theory of Sound," I, p. 473.

[2] Wien. *Annalen d. Phys*, IV, p. 450, 1901.

[3] Kempf-Hartmann. *Annalen d. Phys.*, VIII, p. 481, 1902.

[4] Taylor. PROCEEDINGS A. I. E. E., XXVIII, 1184, 1909.

[5] Gati. *Electrician*, LXVI, p. 456, 1910.

Gati has worked with transmitters. He produced before the diaphragm a sound of which the frequency was varied, but the amplitude was kept as constant as possible. The transmitter was in circuit with a battery and the primary of a transforming coil. To the secondary of the coil he connected the capacity required to produce electric resonance at each frequency and measured the current in the secondary circuit. Plotting curves between frequency and current a decided maximum is obtained showing resonance at about 700 vibrations per second.

The mathematical theory of the free oscillations of circular membranes and plates has been developed. It shows that the nodes are either circles about the centre, or diameters symmetrically distributed[6], this holding true for plates with either a free or a clamped boundary; the boundary of membranes is, of course, necessarily fixed. Rayleigh gives the following formula for the frequency of the lowest natural vibration of a clamped plate.

$$n = \frac{3.2^2 \sqrt{q\,h}}{2\,\pi\,a^2 \sqrt{3\,\rho\,(1-\mu^2)}}$$

where q = Young's modulus.
μ = Poisson's ratio.
ρ = volume density.
$2h$ = thickness of plate
a = radius of plate.

He applies the formula to the case of a receiver diaphragm which he measured and found 991 as the fundamental frequency. No experimental verification of this seems to have been attempted.

OBJECT

The present work was undertaken to obtain further and more accurate information concerning the way in which the diaphragms in the transmitter and receiver vibrate when acted on by periodic forces of simple wave form of different frequencies. Also to obtain quantitative data on the influence of the free periods, and to determine to what degree of approximation the form of the vibration of the diaphragm follows that of the impressed force. The question of the localization of the nodes and loops at the higher resonance frequencies is also interesting, but it has thus far evaded solution.

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[6] Rayleigh. "Theory of Sound," Vol. I, pp. 331, 366.

WORK ON THE RECEIVER

Arrangements and Apparatus. The receiver is simpler in construction than the transmitter and is therefore more easily investigated. With the receiver the problem is to pass through it an alternating current of simple wave form, as nearly simple harmonic as obtainable, and to record the form of the current, and the corresponding oscillation of the diaphragm. The amplitude of the oscillation of the diaphragm for the same current at different frequencies, plotted against frequency would then give the resonance curve for the diaphragm. For producing the alternating currents two special generators with smooth body armatures were used for low frequencies. For the principal range a third generator was used. With these three machines frequencies from 16∼ to 3000 ∼ could be attained. The current wave form was recorded by a Duddell double high frequency oscillograph, used simultaneously as oscillograph and ammeter. An oscillograph of this type has a free period of from 8000 to 10,000. It may hardly be relied upon to record with any accuracy a wave of over three or four hundred cycles. In the present case, however, the current wave is, with a few exceptions, very nearly pure, and the question of wave form does not enter markedly into the results of the work.

The method adopted for recording the oscillations of the diaphragm was as follows: A small fragment of mirror was mounted directly on the diaphragm by means of wax or cement, and its vibrations recorded by a spot of light reflected upon a photographic plate. It is easy to mount the mirror rigidly, and its mass which may be 0.007 of a gram or under, is too small to influence the motion of the diaphragm greatly. There can further be no doubt that the angular deviation of the mirror is the angular deviation of the diaphragm, at the point where it is mounted.

DIAPHRAGM A

The first receiver worked with was one of the ordinary bipolar type. Its characteristics were: Total diameter of diaphragm 5.42 cm. (2.14 in.). Inside diameter of clamping ring in cap 4.98 cm. (1.96 in.), this being the effective diameter of the diaphragm. Thickness of diaphragm with enamel on front face 0.03 cm. (0.012 in.). Thickness bare at edge 0.023 cm. (0.009 in.). Distance between pole pieces and plane of clamping ring of diaphragm 0.05 cm. (0.02 in.). The air gap between pole pieces and diaphragm is less than this as the diaphragm is permanently bent inwards by the attraction of the magnet. The part of the cap extending over the diaphragm was cut out in order to make room for the small mirror which was fastened on. See Fig. 1. The mirror was placed about half way between the center and edge. The diaphragm was so oriented over the pole pieces that the mirror came on the perpendicular bisector as shown in Fig. 2. The receiver was then set up so that the mirror came on a horizontal diameter. Pulling in of the diaphragm corresponded to a motion to the right of the light spot on the photographic plate.

Some of the photographs obtained for this diaphragm are shown in Figs. 3 and 4, with frequencies noted for each set. The curves on the left are the oscillograph records of the current through the receiver, the number at the side giving its value in milliamperes (effective), calculated from a knowledge of the sensibility of the oscillograph. The curves on the right are the traces from the diaphragm, the accompanying figures giving the value of the angular deflection in radians × 10^{-4}, calculated from the dimensions of the optical system. As these latter curves are unsymmetrical it is impossible to speak of their amplitudes, so the total deflection from one extremity of swing to the other is given; this quantity will henceforth be referred to as the "range" of the oscillation. The numbers on the extreme right-hand side of the figure give the frequencies of the vibration in cycles per second. In all of the photographs time proceeds upwards, as shown by the arrow. In the first traces a break is noticeable about the middle of the vibration, which indicates the rest positions of the spots of light. This break was produced by

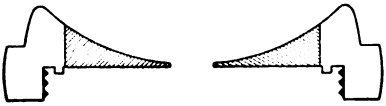


FIG. 1.—CAP OF RECEIVER—THE SHADED PORTION WAS CUT AWAY.

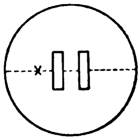
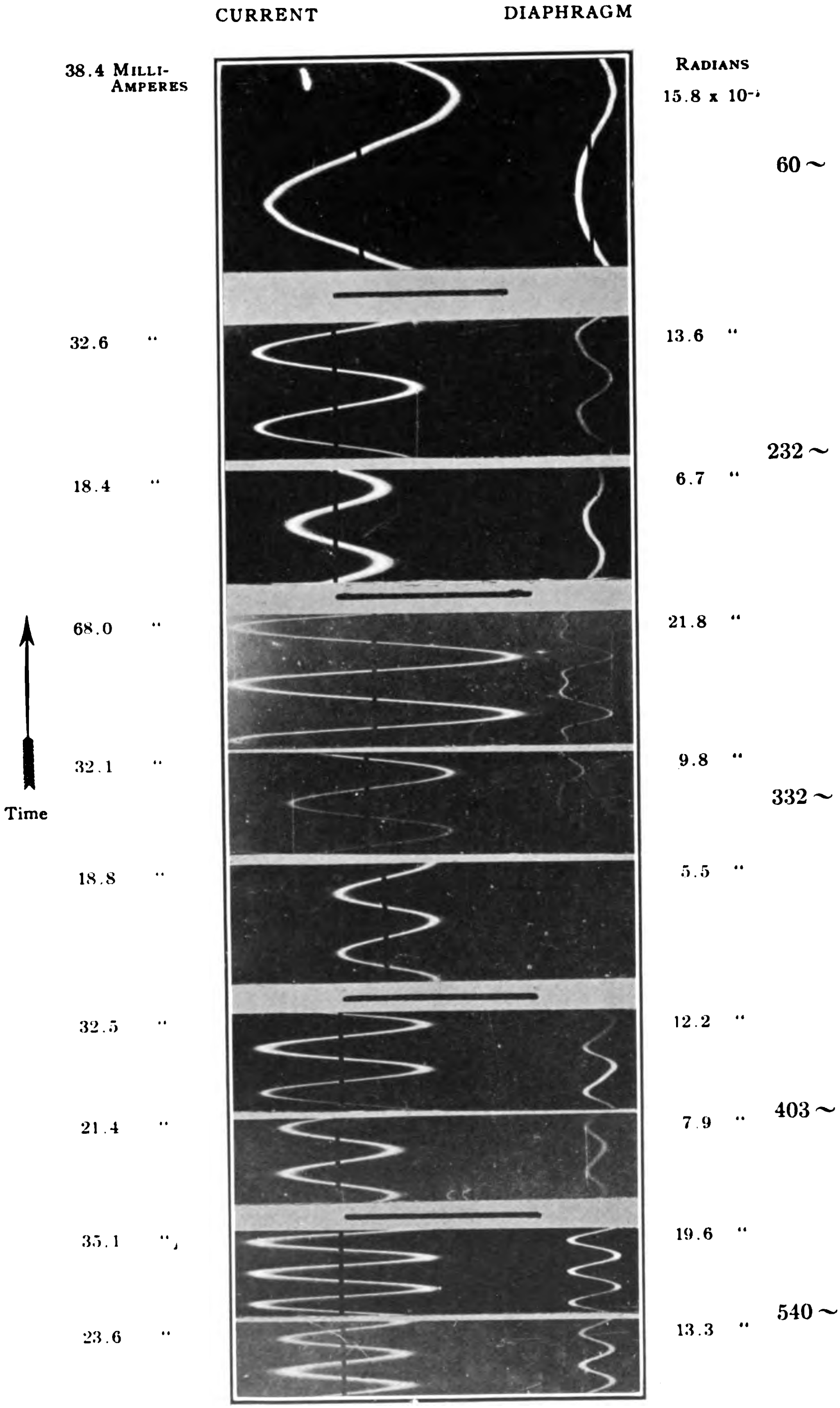
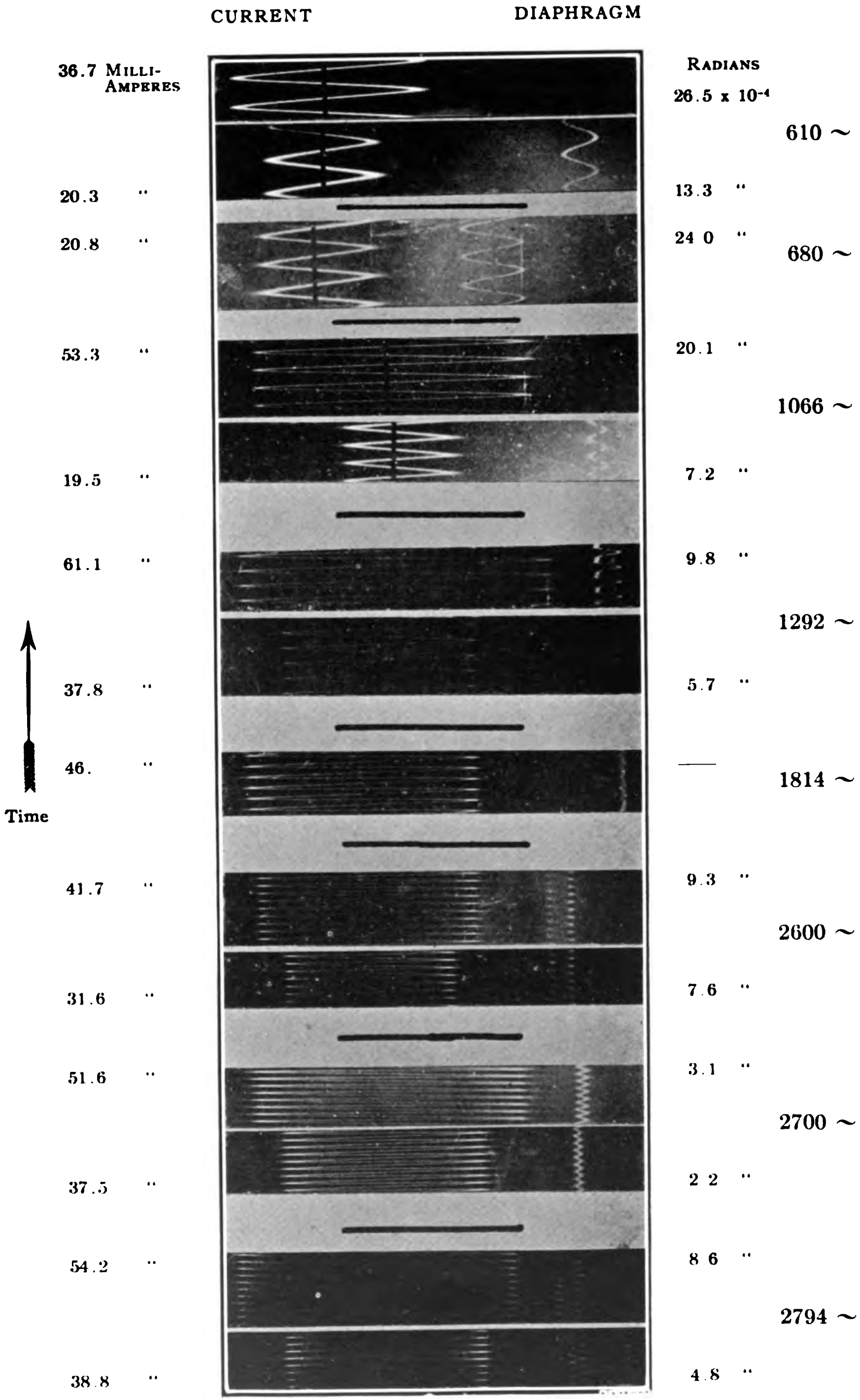


FIG. 2.—THE *X* MARKS THE POSITION OF THE MIRROR ON THE DIAPHRAGM



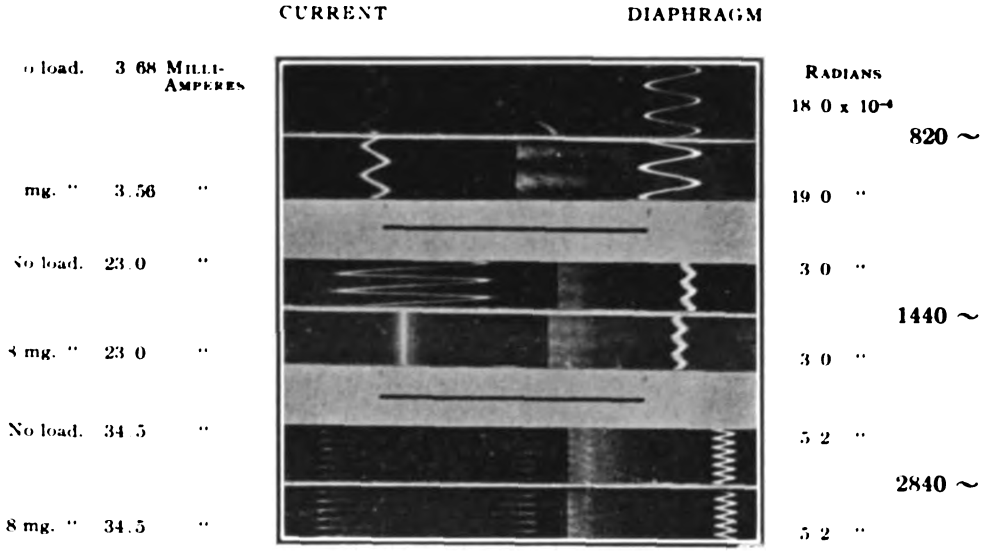
[MEYER AND WHITEHEAD]

FIG. 3—RECEIVER DIAPHRAGM A



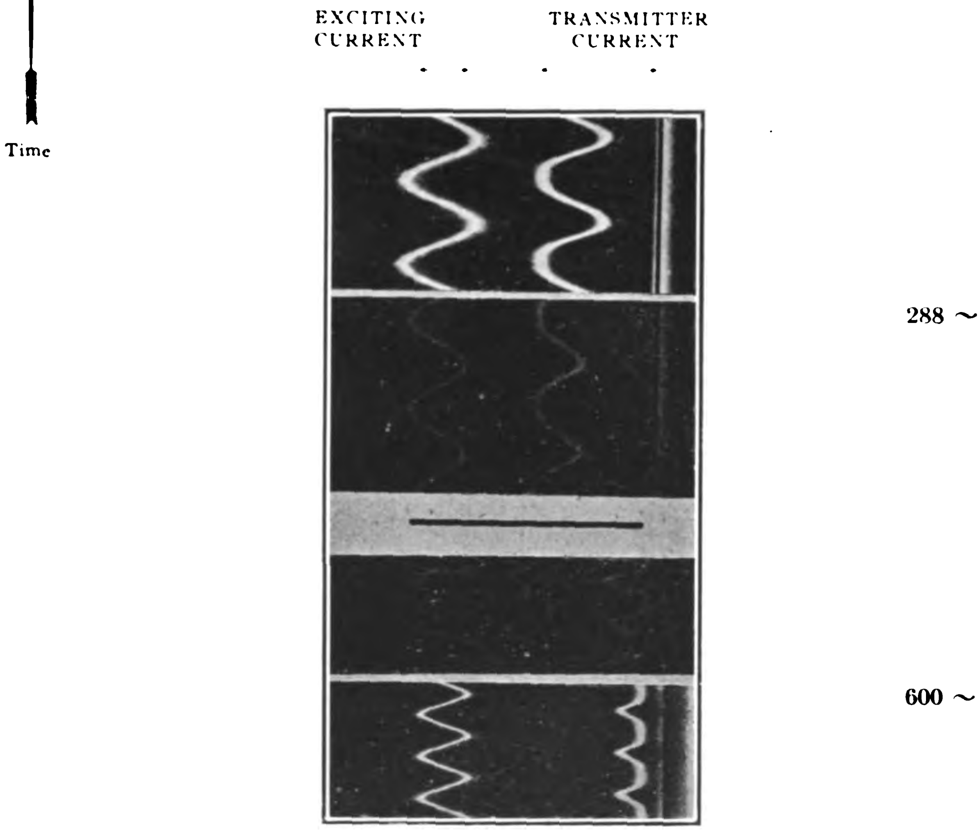
[MEYER AND WHITEHEAD]

Fig. 4—Receiver Diaphragm A



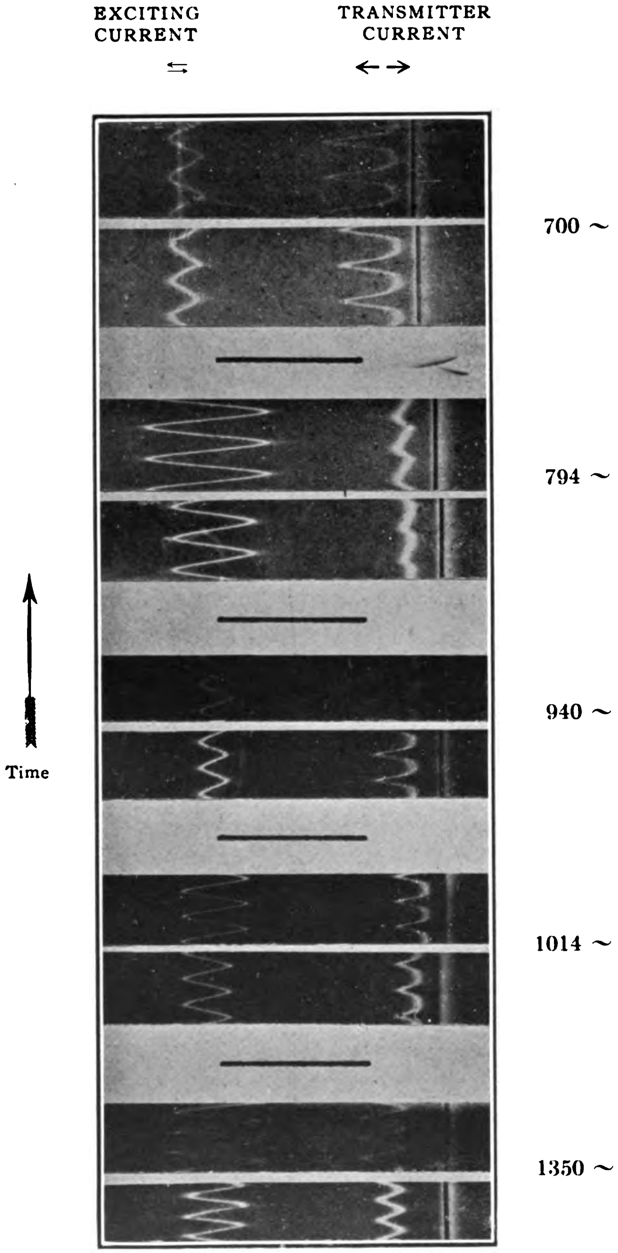
[MEYER AND WHITEHEAD]

Fig. 5—Receiver Diaphragm B



[MEYER AND WHITEHEAD]

Fig. 6—Transmitter



[MEYER AND WHITEHEAD]

FIG. 7—TRANSMITTER

placing a fine wire in the path of the beam of light when there was no current, but the wire was soon abolished as it introduced unnecessary complications.

The diaphragm trace for 60 cycles is seen to be somewhat unsymmetrical the curve being pointed on the right, that is when the diaphragm is nearest the pole pieces. At 232 cycles for a range of 13.6 the curve is rather unsymmetrical, but for a range of 6.7 the irregularity is less marked. At 332∼, and 1292∼ also, the irregularities are seen to be greater for greater ranges while for most of the other curves this is not noticeable. The development of the dimple in the curve for 332 and 1292 ∼ at the point where the diaphragm is furthest from the poles is rather surprising; it will be seen later that 332 ∼ shows a peculiarity in another respect. It might be expected from the following considerations to find greater regularity in the photographs for small ranges.

The force on the diaphragm is proportional to the square of the induction. If we consider the induction B as made up of a constant part B_0 due to the permanent magnetism, and a variable part B_1, due to the current, we have for the original force

$$F_0 = c\,B_0^2$$

and for the variable force

$$F = c\,B^2 = c\,[B_0^2 + 2B_0\,B_1 + B_1^2] \tag{2}$$

The increment of the variable force over the original force determines the motion of the diaphragm. Its value is

$$\triangle F = F - F_0 = c\,[2B_0\,B_1 + B_1^2]$$

If B_1 is sufficiently small we may neglect its square and write

$$\triangle F = 2c\,B_0\;B_1 \tag{3}$$

So that, if B_1 is made to vary harmonically, $\triangle F$ will do so. In the present work the currents have been kept nearly harmonic in all cases. The variation in the air gap between the pole pieces and the diaphragm, would prevent B_1 from being strictly proportional to the current, but for sufficiently small vibrations the influence of the variation in the air gap may be neglected.

The ranges of all the traces were carefully measured. The results obtained for the first diaphragm are plotted in the curves of Figs. 8, 9, and 10. The abscissæ are current through the receiver, expressed in milliamperes (effective). The ordinates are the angular range of oscillation of the diaphragm, expressed in radians $\times 10^{-4}$. Each curve gives the relation between current through the receiver and oscillation of the diaphragm at a given frequency which is marked beside it. The curves are all plotted to the same scale and put in separate figures to avoid crowding. They show that an approximately linear relation exists between the current and deflection of the diaphragm, even to the large values of current here used. The sound of the telephone for the greater currents was sufficient to be heard all over the room.

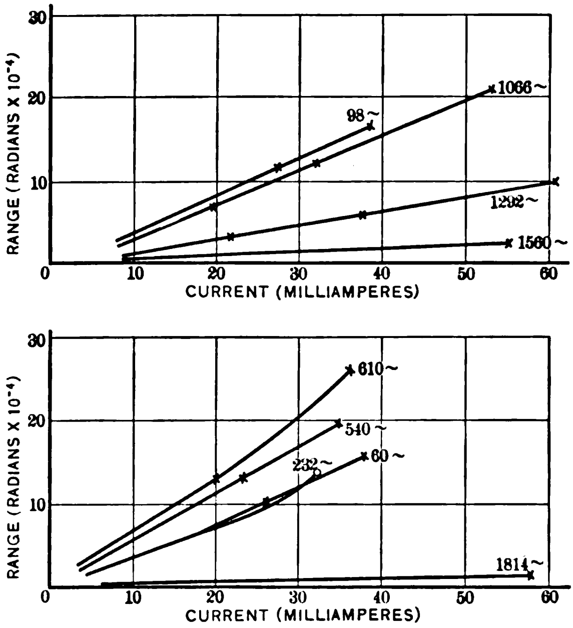


Fig. 8.—Relation between Current through the Receiver, and Range of Oscillations of the Diaphragm at Different Frequencies.

From each of the curves of Figs. 8, 9, and 10, the angular oscillation corresponding to a current of twenty milliamperes, at the frequency for which the curve is taken, can be read off. In Fig. 11 a curve is plotted between the frequency as abscissa, and the angular oscillation as ordinate, showing the effect of change of frequency on the angle of oscillation, this being the so-called resonance curve for the diaphragm. It will be noticed that the curve starts out horizontally, then drops to a minimum at 300 ~ from which it rises and reaches a maximum at 720 ~, at which the range of oscillations is about five times that of the minimum, and about four times that at the lowest frequency. After 720 ~ there is no other maximum until 2600 ~, and then shortly after this there appears to be another, but this was not quite reached as it was not desired to overspeed the machine at the time these records were obtained. It is rather surprising to find the minimum at 300, before the first maximum. At first its real existence was doubted but the appearance of a similar dip in the curve for the next diaphragm, with an entirely different make of receiver, seems to indicate a real effect. It should be remembered that the damping of the diaphragm in a receiver is not purely mechanical, but is partly electromagnetic and this may have a bearing here. The mechanical effect can be expressed

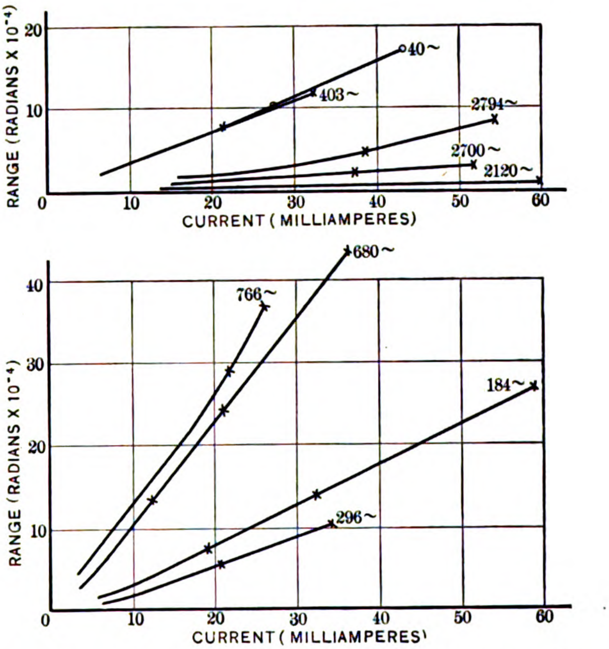


FIG. 9.—RELATION BETWEEN CURRENT THROUGH THE RECEIVER, AND RANGE OF OSCILLATION OF THE DIAPHRAGM AT DIFFERENT FREQUENCIES.

by a term of the usual form $k\ \frac{dx}{dt}$ in the differential equation of motion of the diaphragm. The electromagnetic damping we may consider to be made up of two parts. One of these is due to eddy currents set up by the motion of the diaphragm in the permanent magnetic field. It would be present if the diaphragm were executing free vibrations. This also could be expressed by a term of the form $k\ \frac{dx}{dt}$. The other part is due to hysteresis and eddy currents caused by the current in the receiver. This would increase with the frequency so that we are dealing here not with a constant damping coefficient, as is usually supposed in the treatment of forced oscillations, but with one that increases with frequency. The minimum in the resonance curve appears at about 300 ~ and it is the trace at 332 ~ to which attention was called above, which shows the dimple. The plate

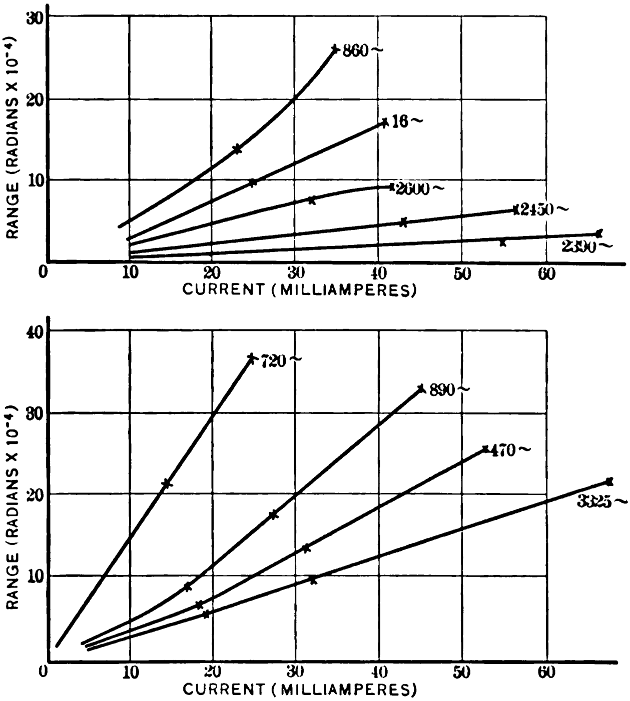


FIG. 10.—RELATION BETWEEN CURRENT THROUGH THE RECEIVER, AND RANGE OF OSCILLATION OF THE DIAPHRAGM AT DIFFERENT FREQUENCIES

for 296 ∼ (not reproduced) was exposed in two sections giving traces very similar to the lower two of 332 ∼. This plate was obtained before the one for 332 ∼ and the range was not carried high enough to get the dimple. It cannot be definitely said that the minimum of the curve and the dimple in the trace are causally connected, but the coincidence is rather striking.

The resonance curve Fig. 11 covers the range of the important frequencies existing in the human voice. The lowest tone reached by man in singing is about 65 vibrations per second. The highest reached by a woman is 1036, but this tone contains harmonics of higher frequencies. A number of investigations have been performed on the vibrations contained in vowel sounds. According to results obtained by Bevier[7] the prominent frequencies are:

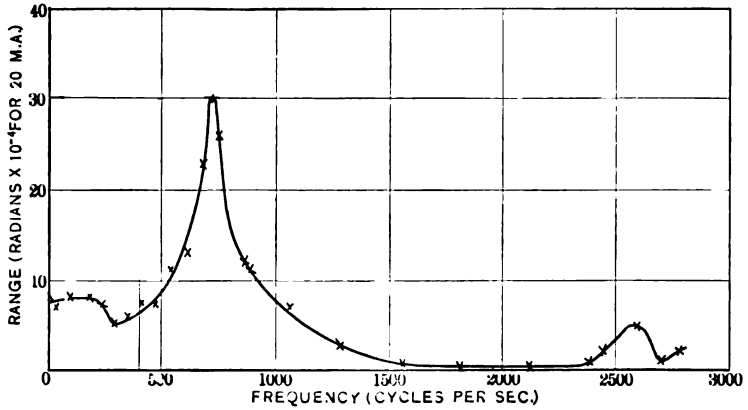


FIG. 11.—RESONANCE CURVE FOR DIAPHRAGM A. GIVING THE RELATION BETWEEN FREQUENCY AND RANGE OF OSCILLATION FOR A CONSTANT CURRENT.

For *a* as in *hat*	650	1050	1550
" *e* " " *pet*	620	1050	1800
" *i* " " *pit*	575	1850	
" *i* " " *pique*			2050

In the consonants, especially those of the hissing type, very much higher frequencies exist, going in some cases as high as 10,000. These consonants have not the importance in speech that the vowels have, and it may well be said that the prominent vibrations are included between 300 and 3000, probably not many lying above 2000.

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[7] *Phys. Rev.*, 1901, 1902, 1903. Quoted by Barton "Text-Book of Sound," p. 672.

We may obtain a comparison between the fundamental frequency of the diaphragm determined experimentally, with that to be expected from Rayleigh's formula. The greatest ordinate of the resonance curve comes at 720. This ordinate for any system lies at a somewhat less frequency than its free vibrations. Further the actual frequency is somewhat less than it would be if there were no damping. It is this last value which is given by Rayleigh's formula. By applying the theory of a system with one degree of freedom to the resonance curve of Fig. 11, a simple calculation shows that if there were no damping the free frequency of diaphragm "*A*" would be 732. This is 12 vibrations a second higher than the point for the maximum ordinate of the curve. The difference is not greater than the error in measuring the frequency. Let us now substitute in equation (1). We may take

$$q = 2.0 \times 10^{12}$$
$$\mu = \tfrac{1}{4}$$
$$\rho = 7.7$$

which gives

$$n = 2.41 \times 10^5 \times \frac{2h}{a^2};$$

from the measurements of the present diaphragm,

$$2h = 0.023 \text{ cm.}$$
$$a = 2.5 \quad \text{"}$$

hence

$$n = 890$$

this being the value required by Rayleigh's formula, whereas the value obtained experimentally is 732. The agreement is not very good but a better result is hardly to be expected. The diaphragm has 0.007 cm. (0.003 in.) of enamel on its front face, which probably loads it down without adding much to its stiffness, thus causing the actual value of the free frequency to be lower than the calculated one. The measurement of the thickness of the diaphragm is not very accurate, only a small spot on the edge being available for this, and moreover the value of Young's modulus substituted in the equation may not be the correct one for the iron of the diaphragm. It cannot be told in what direction more accurate values for these last two quantities would change the result.

DIAPHRAGM B

Another receiver designated as No. 122 *W*, also of the bipolar type, was next investigated. Its characteristics were: Total diameter of diaphragm 5.51 cm. (2.17 in.). Inside diameter of clamping ring 5 cm. (1.97 in.). Thickness of diaphragm over enamel and varnish 0.028 cm. (0.011 in.). Thickness bare at edge 0.023 cm. (0.009 in.). Distance between pole pieces and plane of clamping ring of diaphragm about 0.03 cm. (0.012 in.).

It seemed desirable to ascertain whether the mirror had any noticeable effect on the form or range of the oscillation, so in this set of exposures the current was kept as nearly constant as possible for each plate. One section was exposed with a load of 8 mg. wax placed on the diaphragm as near to the mirror as possible, and the other section was exposed without the load. Some of the photographs are reproduced in Fig. 5. In none of these is there any noticeable difference in wave form when the load is on and off, nor is any difference shown in the other photographs which are not reproduced. The traces were all carefully measured. The differences in width are of the order of the errors of measurement, which range from, say, 5 per cent when the traces are as wide as those for 820 ∼ to 15 or 20 per cent for narrow traces, as for 1440 ∼. The measurements on the same trace usually check up to one or two per cent if the range of the trace is a centimeter or more, but in measuring traces of different photographic intensity the accuracy is probably not so great. The figures for 820 ∼ show an increase of 8 per cent for the loaded case over that for no load; this may be a real effect.

Fig. 12 gives the resonance curve as nearly as it can be plotted from the scant data obtained for this diaphragm. Frequency is plotted as abscissa, and the ratio of diaphragm oscillation to current as ordinate. If we assume the linear relation of current and diaphragm oscillation for a fixed frequency this gives the same curve as Fig. 11 to within a constant factor. We see that the minimum before the first maximum is again present, and in a more marked degree than for the first diaphragm. The maximum ordinate is about five times that at the minimum as before, but only three times that at the lowest frequency. However it is not entirely certain that the maximum comes at 820 ∼ as drawn. When watching the light spots this appeared to the eye to be about the maximum and so the photograph was made at this frequency. If more points had been obtained they might have shown that the maximum really lies at a somewhat different frequency, and has a 10 or 20 per cent greater value. The curve shows no further resonance points up to the highest speed the machine attained, but they doubtlessly would have been found if it had been possible to go high enough. This diaphragm had approximately the same characteristics as the first so if we apply Rayleigh's formula we again get 890 as the natural frequency, the agreement with the experimental value being somewhat better this time.

General Observations

More diaphragms, and diaphragms of different characteristics might have been examined by the method here used, but it was thought that before the investigation was extended in this direction further knowledge should be obtained about the motion of some one diaphragm. It was pointed out above that when a circular plate is vibrating freely, the nodes are circles and diameters.[8] In the case of a clamped diaphragm this means that the nodes may be located as shown in Fig. 13. These drawings are for the five lowest modes of vibration and are given in the order of ascending frequency. We may expect that in the case of a telephone diaphragm some of these types of vibration will be present. It cannot be said in advance which ones will occur nor to what extent they will do so. This depends on the frequency of the impressed force and on the way in which it is applied, and can only be found by experiment. Hence we may suppose that

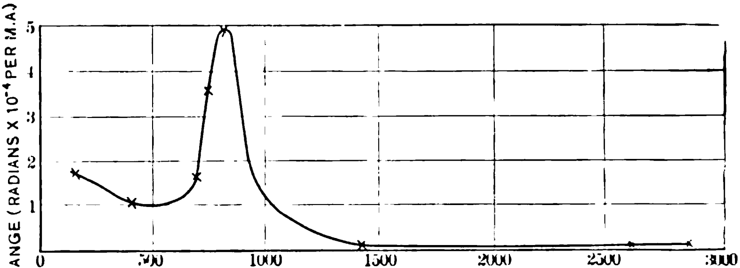

Fig. 12.—Resonance Curve for Diaphragm B.

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[8] Winkelmann's "Handbuch der Physik, II," p. 372, ed. 1909. Rayleigh. "Sound," Vol. I, pp. 331 and 366.

by fixing a mirror in one spot (*e.g.*, over the perpendicular bisector of the pole pieces), we cannot learn all that should be known about the motion of the diaphragm, and this is borne out, even to a more marked degree than was expected, by visual observation of the spot of light at certain frequencies. The spot ordinarily vibrated in a horizontal direction. This is what would be expected if the vibration consisted of a motion of the diaphragm as a whole (Fig. 13*a*,) or if there existed an internal circular node (Fig. 13*d*,). We may refer to this as a " circular " vibration. At certain frequencies the spot of light vibrated, not horizontally, but obliquely. An oblique motion would be produced

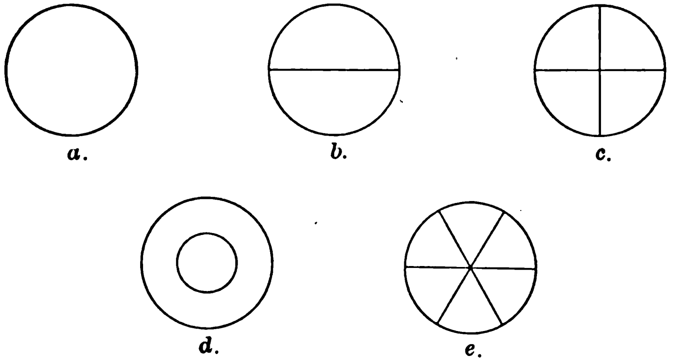

FIG. 13.—REPRESENTING THE FIVE LOWEST MODES OF FREE VIBRATION OF A CIRCULAR DIAPHRAGM.

a.—The boundary as the only node—diaphragm vibrating as a whole.
b.—One diameter as node—the two halves of the diaphragm vibrating in opposite phase.
c.—Two diameters as nodes—adjacent quadrants are in opposite phase.
d.—Two circles as nodes—the inner and outer areas are in opposite phase.
e.—Three diameters as nodes—adjacent sectors are in opposite phase.

if there were superimposed on the circular vibration a vibration having one or more diameters as nodes, as in Fig. 13 *b c*, or *e*. We may speak of this motion as a " diametral " one. The mirror need not be located on a node to show this component, but would do so to some extent if it were located anywhere except on a loop. This component cannot be symmetrical about the center of the diaphragm.

It is not at once evident why the diametral vibration should be introduced at all. If we assume the complete symmetry of the diaphragm about its center, and of the pole pieces about the diameter bisecting them perpendicularly, there is no reason to expect it. We must look for a lack of symmetry somewhere. The mirror on the diaphragm suggests itself, but the weight of the mirror was only 4 mg. and it seems improbable that so small a load could be responsible for the vibration. It was thought that some sort of asymmetry must exist in the poles, and if this were the case then a rotation of these behind the diaphragm ought to make the nodal diameter rotate in the diaphragm, keeping a fixed position with reference to the poles. This would allow an exploration of the motion, so to speak, around the diaphragm without moving the mirror or the diaphragm itself. A receiver (122 *W*) exactly like the one used with diaphragm "*B*" was fitted up to allow the rotation of the poles. With this instrument it was found that the diametral component recorded by the spot of light changed markedly as the pole pieces were rotated; it passed from zero through a maximum and back to zero in about half a revolution. But it was also noticed that there was a decided change in the intensity of the sound as the rotation took place, which, of course, should not exist if the diaphragm were symmetrical and the nodal diameter were merely being turned therein. Moreover the maximum diametral components recorded by the image coincided with the maximum sound, so that possibly the main thing shown was that the amplitude of the diametral vibration of the whole diaphragm depended on the orientation of the diaphragm over the poles. Three things presented themselves in explanation of this fact: First, mechanical imperfections in the rotating part might cause the poles to approach the diaphragm in certain positions and recede at others. Second, the influence of the weight of the mirror might make one direction in the diaphragm different from another. Third, the grain of the diaphragm may be the cause. This was suggested by Kempf-Hartmann[9] as a possible cause of asymmetry. Some rough experiments were at once instituted to decide between these three possibilities, and it is certain that mechanical imperfections play only a small part if any at all. No decision could be made between the influence of the mirror and grain, but it is thought that this can be done in the future. If it develops that the orientation of the grain in the diaphragm over the poles plays an important part in determining to what extent the diametral vibrations are introduced, it would appear to be a matter of some importance.

Whether these vibrations are a help or a hindrance in the transmission of speech it is difficult to say. It is generally considered that the fundamental tone of the diaphragm falls within the range of the principal frequencies of the voice, and this is borne out by comparison of the curves of Figs. 11 and 12 with the data given on the frequencies for different sounds. The amplitude of the circular vibration is small between the fundamental and the next higher resonance tone. Sounds of certain pitch are therefore very much magnified in relation to others. The frequencies of the vibrations with one diameter and two diameters as nodes lie below the frequency for the second circular vibration. From the observations discussed above it appears that a telephone diaphragm may be made to take up these nodes of vibration by properly orienting it over the pole pieces or by properly loading it. Now, might it not be possible by deliberately introducing the diametral vibrations, both in transmitter and receiver, and choosing the sizes of the diaphragm in such a manner than the maxima of the resonance for the one diaphragm, coincide with the minima of the resonance for the other, to maintain more nearly the relation between the amplitudes of sounds of different frequencies?

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[9] Kempf-Hartmann. *Annalen*, VIII, p. 492, 1902.

WORK ON THE TRANSMITTER

Arrangements and Apparatus. For the transmitter the general problem is similar to that for the receiver, namely, to exert an oscillating force of known form on the diaphragm and record the vibration produced by it. As in actual use the transmitter is acted on by sound waves, the most natural thing would be to use these for the impressed force, but experimental difficulties arise which make this impracticable. It is difficult, if not impossible, to get a source of sound which is sufficiently loud, and at the same time gives a pure tone of which the pitch and intensity may be easily varied and measured over a wide range. Moreover when working with sound sources in an enclosed space, such as the room of a laboratory, there are always standing waves set up between the walls of the enclosure which would introduce a further uncertainty in determining the intensity of the sound which is incident upon the transmitter diaphragm. For these reasons no attempt was made to use a sound source. From the work on the receiver the conclusion seemed justified that the pull produced on the diaphragm by the receiver magnet is nearly harmonic for a harmonic current, and the amplitudes of the force and current are proportional if the current is not too great. It was accordingly decided to use a receiver magnet for producing the force acting on the transmitter diaphragm, as this allows the frequency and amplitude to be easily varied and measured. The magnet of a receiver was mounted rigidly in front of the transmitter. A small iron disk was shellaced on to the diaphragm to have some magnetic material for the magnet to act on, as the transmitter diaphragm themselves are of aluminum. The necessity of using the disk and the fact that the magnet produces a central force instead of a distributed one, as does a sound wave, are disadvantages of this method. (The weight of the disk was 0.81 gram.)

The current from the alternating current generator was passed through the coil of the receiver magnet, and the current wave recorded on the oscillograph. For recording the vibration of the diaphragm the mirror method would have had certain advantages, but with a system as stiff as the transmitter the amplitude would not be great enough. Current from a storage battery was passed through the transmitter and the second vibrator of the oscillograph in series, and the variation of current in the transmitter due to the vibration of the diaphragm was recorded on the same photographic plate on which the curve of the current through the magnet was recorded; the variation of current in the transmitter was taken as a measure of the oscillation of the diaphragm. The electrical connections are shown in Fig. 14. In one electrical circuit which will hereafter be referred to as the "magnet circuit," the high frequency generator *G*, the oscillograph O_1, the coil on the magnet *F* and the resistance *R* are in series. In the other circuit which will be called the "transmitter circuit," the current flows from the storage battery *B* to the diaphragm *D* through the carbon granules box of the transmitter *C* to the oscillograph O_2, and through the milliammeter *A* back to the battery. The battery consisted of three storage cells; the voltage remained constant at 2.9 volts throughout. The two circuits

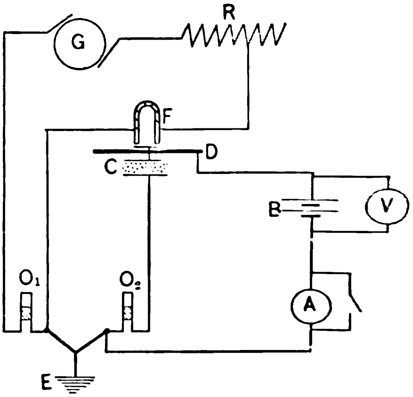

FIG. 14.—ELECTRICAL CONNECTIONS IN WORKING WITH THE TRANSMITTER.

had the point E in common at which they were connected to earth. The action of the apparatus is simple. The alternating current in the coil of the magnet F causes the diaphragm D to vibrate. Before the beginning of the vibration the current in the transmitter is steady and can be read on the milliammeter A. This steady current causes a steady deflection of the oscillograph O_2. When the motion of the diaphragm begins the current undergoes variations which are recorded by O_2. During the time of making an exposure the milliammeter is shunted so as to do away with all possible self induction in the transmitter circuit.

PHOTOGRAPHS AND MEASUREMENTS

Some reproductions of the photographs are shown in Figs. 6 and 7. The trace on the left shows the current in the magnet coil. The zero line is not shown but would traverse the middle of the trace as this is due to a simple alternating current. The straight dark line on the right gives the line for zero current in the transmitter. The trace to its left gives the variation of current through the transmitter when the diaphragm is oscillating. That is, the distance from the zero line to the trace at any point gives the instantaneous value of the current, and the difference between the maximum and minimum distance gives the range of oscillation of the current. The frequencies are given to the right.

On the plates for 600, 700, 940 and 1014 cycles, and on most of the plates not reproduced, the traces are pointed for maximum current (granules compressed) and flat for minimum current. In these cases the steady current line runs nearer the minimum than the maximum. This was shown by an asymmetrical broadening of the light spot toward the left when the exciting current was turned on, and also by a rise in the reading of the milliammeter A. In the first plate shown, namely for 288 cycles, this is reversed. The points are for minimum current and the flat side for maximum. In this case the steady current line runs nearer the maximum, the broadening being asymmetrical to the right, and correspondingly, the milliammeter fell on making the exciting current. The plate for 1350 cycles gives a more symmetrical trace of 288 ~, but showed the same anomalous behavior in the broadening of the light spot toward less current, and the dropping of the milliammeter. These two plates were taken one after the other. This anomalous condition had been observed visually on one occasion when observing the oscillations by means of a ground glass and a rocking mirror, but the transmitter had gone back to its normal condition before a photograph was obtained. After this no amount of tapping and exciting would bring it back. The plates in question were obtained when at the end of a series of exposures this condition was found to exist accidentally. After these two plates the transmitter returned to its normal state. Later one more anomalous trace was obtained at 660 but this does not fit in well with the others. The peculiarity did not seem to occur at any definite frequency, but seemed to depend entirely on the arrangement of the granules, for when once present it showed over a wide range of frequency, and when absent the same frequency could be gone over with normal results. It is not to be confused with ordinary "packing" but may be

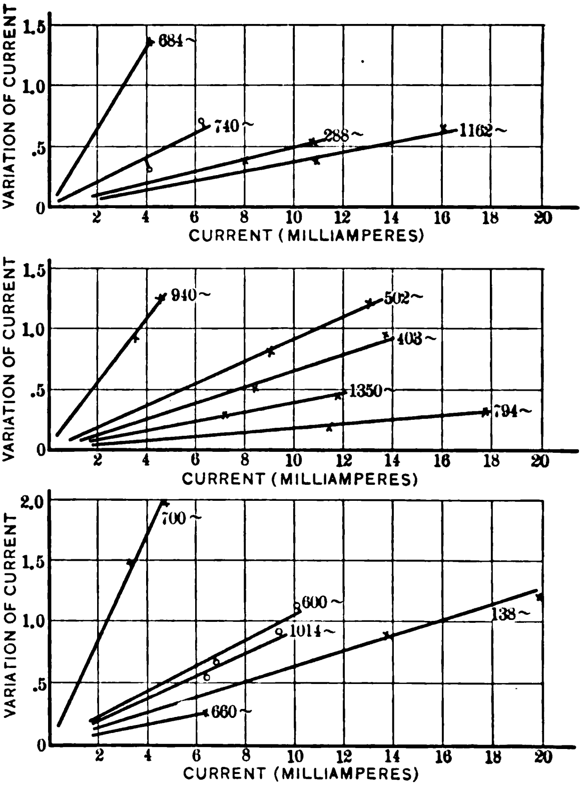

FIG. 15.—RELATION BETWEEN CURRENT THROUGH THE COIL OF THE MAGNET, AND THE VARIATION OF THE CURRENT THROUGH THE TRANSMITTER.

closely allied to it. The traces for the transmitter in general show a great deal more distortion than do those for the receiver. The actual range of force on the diaphragm is considerably less for the transmitter, as the air gap between the magnet and disk is greater, and the amplitude of the current in the magnet is less.

Plotting for each frequency the current in the magnet as abscissa, and the variation of current in the transmitter, per milliampere of steady current as ordinate, we get the curves of Fig. 15. This relation between the two is seen to be approximately linear. The point farthest out usually shows a somewhat steeper slope, but in several cases the reverse is true. The accidental errors due to changes in the transmitter are, of course, great, so a straight line running between the two points was considered a fair locus for the curve. In Fig. 16 a curve is plotted having frequencies as abscissas, and as ordinates the variation of current in the transmitter per milliampere of steady current, when the current in the magnet has a constant value of four milliamperes. This is the resonance curve for the diaphragm. The points all fall fairly well into line except the one for 660 $\sim$, which is the one exposure made when the transmitter was for the second time in the anomalous state. The two plates obtained when it was for the first time in this state fall into line very well. The resonance curve certainly does not include the point at 660 $\sim$, as the light spots were watched vis-

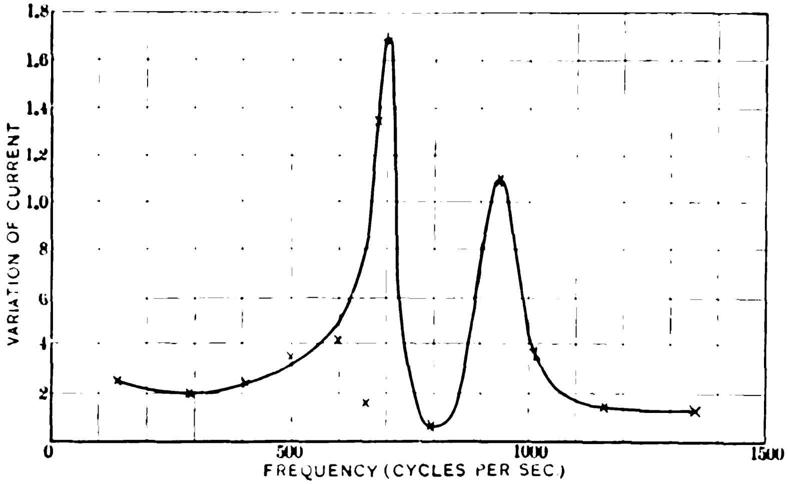

FIG. 16.—RESONANCE CURVE FOR THE TRANSMITTER.

ually, when the granules were in normal condition, and no drop in amplitude at that frequency was ever noticed. The light spots were watched time and again as the generator accelerated or came to rest; and it was easy to see the marked continuous rise and fall in the width of the oscillation. Whatever errors may have crept into the determination of one or two of the points the general nature of the resonance is certainly that of Fig. 16.

We notice in the curve the slight fall before the first maximum which was present in the receiver diaphragm curves, and is probably due to the losses in the magnet. Next the sharp maximum at 700, the minimum at 800, the second maximum at 940, and after this the drop to a fairly constant value. It is regretted that the investigation could not be pushed above 1350; but at higher frequencies conditions became very unsteady, especially is this true of the average current through the transmitter. It is a great surprise to find such sharp maxima in the curve, and two so close together. The ordinate of the first maximum is seen about eight and a half times that at the minimum, and six and a half times that at the lowest frequency; at the second maximum about eighteen times that at the minimum just before it, and about four times that at the lowest frequency. The location of the fundamental vibration at 700 cycles is in good agreement with Gati's work. It is to be regretted that no data can be obtained from his results regarding the sharpness of the resonance. His curves having as ordinates the current in a secondary circuit have a zero ordinate for zero frequency, *i.e.*, they start from the origin. Hence no comparison between the amplitude at resonance with that at zero frequency can be made.

The first resonance of the diaphragm we would naturally suppose to be due to its vibration as a whole. The second may be introduced by one of the so-called damping springs. The diaphragm in most modern transmitters, and in the one here worked with, is held in place by two pieces of spring steel about $\frac{3}{8}$ in. wide $1\frac{1}{2}$ in. long and 0.01 thick. These have rubber tips on the ends. One presses against the diaphragm at the edge; and the other one, some distance in towards the center. Now the point where the second one presses is more firmly supported than the points in its vicinity, so the second resonance may be due to a vibration of irregular configuration with this point lying on a nodal line. If this is the case one of the actions of the damping springs is just the opposite to that commonly supposed. According to Kempster B. Miller:[10] "The object of these damping springs is to prevent too great an amplitude of vibration of the diaphragm, and also to keep it from vibrating in separate parts instead of as a unit." The inside damping spring may also have considerable influence in raising the fundamental period of the diaphragm as it adds to its stiffness. It should be possible to settle these questions by placing both springs on the edge and taking another resonance curve. It is hoped to do this in the near future.

SUMMARY OF RESULTS

Photographs have been obtained showing the vibration of receiver diaphragms when approximately harmonic currents are passed through the receiver. These show considerable distortion at some frequencies and very little at others. At any one frequency the distortion is less for smaller currents. This is what would be expected from *a priori* consideration.

An approximately linear relation has been shown to exist between current and amplitude of oscillation of the diaphragm over the range of work, which extends well beyond that of practice. Resonance curves for two receiver diaphragms have been plotted giving quantitative data of the influence of the natural period of the diaphragm.

The effect of a small load on the form and range of the oscillation was examined. Its influence could not be detected except in one instance in which there was possibly a slight effect on the range of oscillation.

Diametral vibrations of the diaphragm were observed in cases in which they would not have been expected from the apparent symmetry of the instrument. The orientation of the diaphragm over the pole pieces was observed to have a marked effect. It has not been experimentally settled whether this is due to the mirror or the grain of the plate, but it is difficult to see how a mirror weighing only 4 mg. could cause the vibrations. It is suggested that by properly introducing " diametral " vibrations the transmission of speech might be improved.

Photographs have been obtained showing the variation of current in the transmitter when an approximately harmonic force acts on the diaphragm. These show a rather marked distortion even for the lowest exciting force used, which was very much lower than the lowest force used on the receiver diaphragm.

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[10] American Telephone Practice. 4th edition, p. 56.

These distorted curves may be just reversed from their normal form when the microphone is in a certain abnormal state.

An approximately linear relation exists over the range examined between the variation in current and the exciting force. The resonance curve of the transmitter is given showing very marked maxima and minima. The first maximum is attributed to the fundamental period of the diaphragm vibrating as a whole. The second maximum is attributed to the diaphragm vibrating in an irregular configuration on account of the damping springs.

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THE SQUIRREL-CAGE INDUCTION GENERATOR

BY H. M. HOBART AND E. KNOWLTON

A careful examination of the various attributes of the induction generator discloses its appropriateness for certain classes of work. It is the purpose of this paper to describe these attributes and to endeavor to deduce therefrom the correct economic field for such machines.

In the design of induction generators, attention must be given to certain matters which do not come in for consideration in the design of *synchronous* generators. Notable amongst these is the requirement that the machine shall have a fairly short air gap, whereas it is usually preferable that the air gaps of synchronous generators shall be of considerable radial depth. In the induction generator the fairly short air gap is rendered essential by the circumstance that the magnetomotive force occasioning the flux is provided in the same windings which supply electricity to the external circuit. The current in the stator windings is the resultant of this exciting current and of the main current delivered to the load. The greater the air gap, the greater is the m.m.f. required to overcome its reluctance and the greater, consequently, is the exciting component of the total current in the stator windings.

It is not alone with the object of reducing to a minimum the total current in the stator windings corresponding to a certain output, that we strive to minimize the exciting current, but it is also with the object of decreasing the size (and cost) of the apparatus from which this exciting current is obtained.

Let us assume the case of a certain induction generator, in which the exciting current per phase (at full load) is 35 amperes and the current output from the machine at full load is 100 amperes. These component currents and their resultant are shown in Fig. 1, and it is seen that the resultant current in the stator windings is

$$\sqrt{35^2 + 100^2} = 106 \text{ amperes}$$

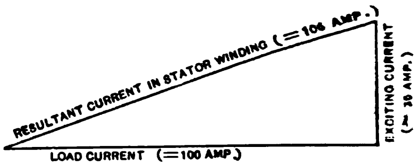
RESULTANT CURRENT IN STATOR WINDING (=106 AMP.)
EXCITING CURRENT (=35 AMP.)
LOAD CURRENT (=100 AMP.)

FIG. 1.—DIAGRAM SHOWING COMPONENT AND RESULTANT CURRENTS IN THE WINDINGS OF ONE PHASE OF AN INDUCTION GENERATOR.

The I^2R loss in the stator windings is 12 per cent greater (since $1.06^2 = 1.12$) than would be the case had the windings only to carry the main current of 100 amperes. Nevertheless this superposition of the exciting and main currents is economical, for if two independent windings were provided for them as indicated in Fig. 2, it would be necessary to provide an aggregate carrying capacity for $(100 + 35) = 135$ amperes in these two windings, whereas the carrying capacity of the single winding indicated in Fig. 3, need only be proportioned for 106 amperes. Or, for the same aggregate weight (and outlay) for copper in the two cases as indicated in Fig. 4, the losses would be proportional to

$1.35^2 = 1.82$ for the two independent windings as against only

$1.06^2 = 1.12$ for the single winding.

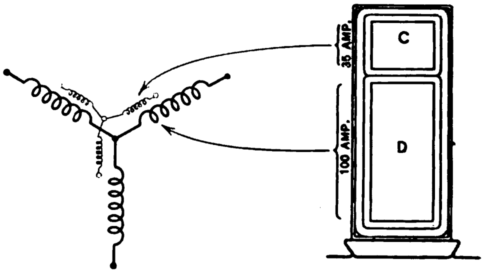

FIG. 2.—SKETCH OF STATOR SLOT AND DIAGRAM OF STATOR WINDINGS OF A HYPOTHETICAL THREE-PHASE INDUCTION GENERATOR PROVIDED WITH SEPARATE WINDINGS FOR THE MAIN CURRENT AND THE EXCITING CURRENT.

A single winding is always employed, not only for this reason but on account of the high degree of simplicity attending the operation of such generators. But since it may be of interest to engineers who have not heretofore given much thought to the subject of induction generators, there are shown in Figs. 5 and 6, the connections which would correspond to the two respective arrangements which have been mentioned.

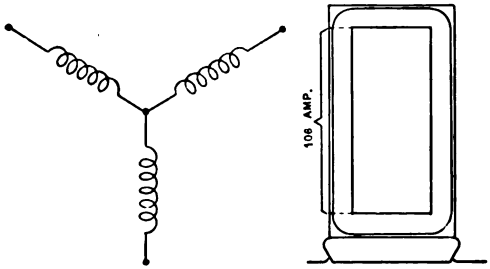

FIG. 3.—SKETCH OF STATOR SLOT AND DIAGRAM OF STATOR WINDINGS OF A THREE-PHASE INDUCTION GENERATOR PROVIDED IN THE USUAL WAY WITH A SINGLE WINDING IN WHICH THE MAIN AND EXCITING COMPONENTS OF THE CURRENT ARE SUPERPOSED.

In Fig. 5, the exciter *A* is shown as a synchronous polyphase generator. The excitation for *A* is, in turn, provided by the direct current generator *B*. The polyphase exciter *A* supplies 35 amperes to the independent exciting winding *C* of the induction generator. *D* is the main winding of the induction generator and it delivers 100 amperes to the step-up transformers *E* of

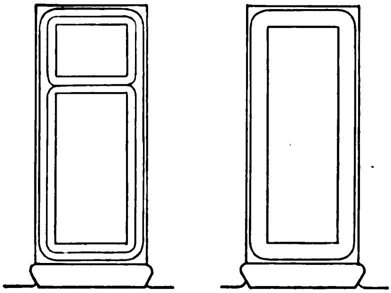

FIG. 4.—SKETCHES OF SLOTS AND WINDINGS FOR TWO CASES, RELATING RESPECTIVELY TO TWO INDEPENDENT WINDINGS FOR THE EXCITING AND MAIN CURRENTS AND TO A SINGLE WINDING IN WHICH THESE CURRENTS ARE SUPERPOSED.

The I^2R loss in the first case (represented at the left) is 62 per cent greater for a given load, than in the second case (represented at the right).

a three-phase transmission system *F*. In Fig. 6 the synchronous generator *A* is shown as not only supplying the excitation to the induction generator *I*, but as also supplying current, through step-up transformers *G*, to the three-phase transmission system *F*. If the synchronous generator *A* also delivers 100 amperes to its step-up transformers in addition to the 35 amperes of excitation which it supplies to the induction generator *I*, then the current in its windings (if the 100 amperes is at unity power factor) will be

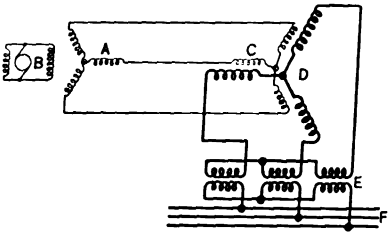

FIG. 5.—CONNECTIONS FOR OPERATING A HYPOTHETICAL INDUCTION GENERATOR PROVIDED WITH A SEPARATE WINDING FOR ITS EXCITATION, THE EXCITATION BEING SUPPLIED FROM A SMALL SYNCHRONOUS MACHINE.

C is the induction generator's exciting winding; *D* is its main winding; *A* is the synchronous exciter and *B* is the latter's continuous current exciter.

$$\sqrt{100^2 + 35^2} = 106 \text{ amperes.}$$

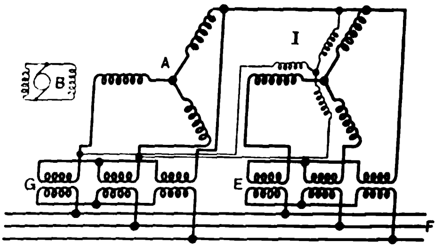

FIG. 6.—CONNECTIONS FOR OPERATING A HYPOTHETICAL INDUCTION GENERATOR I WITH SEPARATE EXCITING AND MAIN WINDINGS, IN PARALLEL WITH A SYNCHRONOUS GENERATOR *A*, THE LATTER ALSO SUPPLYING THE EXCITATION FOR THE INDUCTION GENERATOR.

Consequently although the supply from the synchronous generator *A* to the transmission system, is at unity power factor, nevertheless the power factor of the resultant load on *A* is only

$$\frac{100}{106} = 0.944$$

As already stated, the induction generator is never, in practice, furnished with two independent windings for carrying respectively the magnetizing current and the main current. On the contrary, it is invariably supplied with only one winding and this winding carries the resultant current. The arrangement is shown in Fig. 7. The induction generator *I* still obtains its excitation from the synchronous generator *A*.

The supply of the wattless component devolves entirely upon the synchronous generator *A*. Let us consider the case of 200 amperes delivered at 0.80 power factor to the transmission system. We may proceed as follows:

Energy component = 0.80 × 200 = 160 amperes

Wattless " = $\sqrt{200^2 - 160^2}$ = 120 amperes.

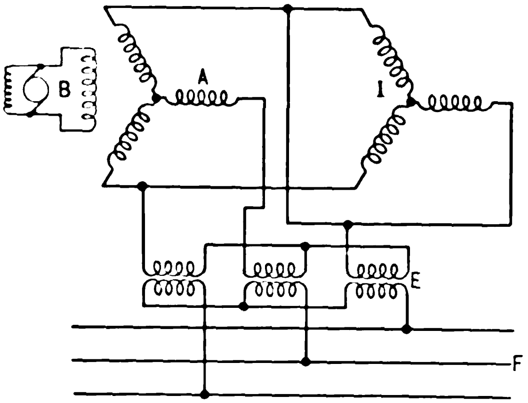

Fig. 7.—Connections Usually Adopted for an Induction Generator *I* Operated in Parallel with a Synchronous Generator *A*.

If the induction generator's capacity is only 100 amperes output and 106 amperes input (the figures we have taken up to this point), then the synchronous generator must provide to the transmission line not only an energy component of 160 − 100 = 60 amperes but also a wattless component of 120 amperes. Furthermore it must provide to the induction generator a wattless component of 35 amperes. Thus the synchronous generator's total output is made up of an energy component of 60 amperes and a wattless component of 120 + 35 = 155 amperes. The resultant current from the synchronous generator is consequently

$$\sqrt{60^2 + 155^2} = 166 \text{ amperes.}$$

Furthermore this current is supplied at a power factor of only

$$\frac{60}{100} = 0.36$$

We have now roughly examined two cases. These have both related to the supply of 200 amperes to a transmission system. In the first case this 200 amperes was at unity power factor and in the second case it was at a power factor of 0.80. In both cases the induction generator supplies 100 amperes at unity power factor. In the first case it devolves upon the synchronous generator to supply 106 amperes at a power factor of 0.944 and in the second case, 166 amperes at a power factor of 0.36. For the second case the synchronous generator would be required to have a thermal capacity for a 57 per cent greater kilovolt-ampere output than in the first case. The point to be noted is that the induction generator's limitation that it can only deal with a unity power factor load has for a consequence that the synchronous machines with which it operates in parallel must bear the burden of providing not only the entire wattless component of the load on the transmission system, but also the magnetizing current for the induction generator. In many instances, however, the circumstances are much more favorable than in the case taken for the purpose of the above explanation.

These examples emphasize the point that the induction generator is, in general, much less useful in connection with supplying a circuit connected to a load of low and lagging power factor than it is for supplying unity power factor circuits. As will be made clear in the course of this paper, while the economic field for the induction generator is not necessarily exclusively limited to the supply of electricity to unity power factor circuits, nevertheless the requirements are more appropriately met by including in the generating station equipment a certain proportion of induction generators, when the supply is for a unity power factor system, or better still, for a system in which the power factor is less than unity and the current leading.

So let us first consider the case of a large generating station for the supply of 60-cycle electricity to synchronous substations.

For the high speeds corresponding to the preferable design of steam turbines, the induction generator is, in most respects, pre-eminently appropriate not only as regards its electrical but also its mechanical characteristics. Let us fix ideas by taking the case of a 5000-kw. unit for 60 cycles. Such a unit would be designed for a speed of either 1800 rev. per min. in which case the generator would be designed with four poles, or else a speed of 3600 rev. per min. would be employed, the generator being designed for two poles. In the former case, the generator could be either of the synchronous or of the induction type. In the latter case (*i.e.*, when employing only two poles) while a design of the synchronous type presents such grave difficulties that 3600 rev. per min. machines are rarely built for more than one-half this rating, the conditions are in most respects especially favorable for the design of an induction generator. Figs. 8 and 9 show the rotor construction of the synchronous and induction generators respectively. The smaller amount of copper and the absence of insulation, end connections, slip rings and brushes greatly simplifys the mechanical construction of the induction rotor.

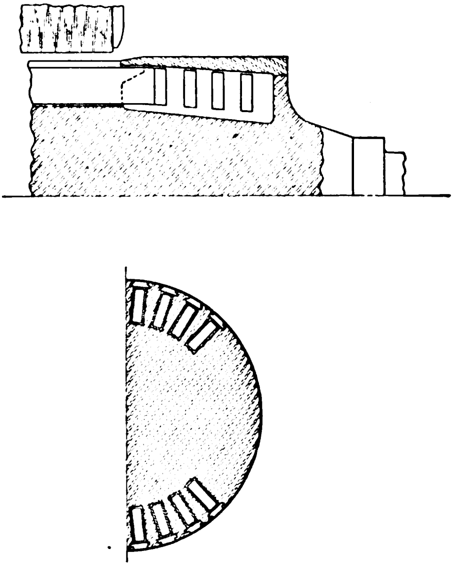

Fig. 8.—Typical Construction for a Bipolar Synchronous Generator.

The advantages of employing for this output (5000 kw. at 60 cycles) a speed of 3600 rev. per min. relate to the lesser weight lower cost, or lower steam consumption of such a set as compared with a set for the lower speed of only 1800 rev. per min.

Some estimates have been made regarding the cost of a complete turbo-generator set comprising such a 5000-kw. bipolar, 3600 rev. per min. induction generator. Representing this cost by 100, the cost of a turbine-driven *synchronous* set for the same output of 5000 kw. at unity power factor but having four poles and operating at a speed of 1800 rev. per min. works out at 125. But the power factor of high speed induction generators will be of the order of 0.95 to 0.97 (according to the radial depth of the air gap) and hence even when the power factor of the system supplied by the generating station is unity, nevertheless the synchronous generators will have a power factor of less than unity since they must supply the magnetizing current for the induction generators. If we instal 5000-kv-a. sets and if we have the same number of induction and synchronous generators, *i.e.*, if we have one synchronous generator for each induction generator and if the load on the station at any time is equally divided between the two types, then the load on the synchronous generator will be of the order of, say, 0.95 power factor. When the generator is designed for an output of 5000 kw. at 0.95 power

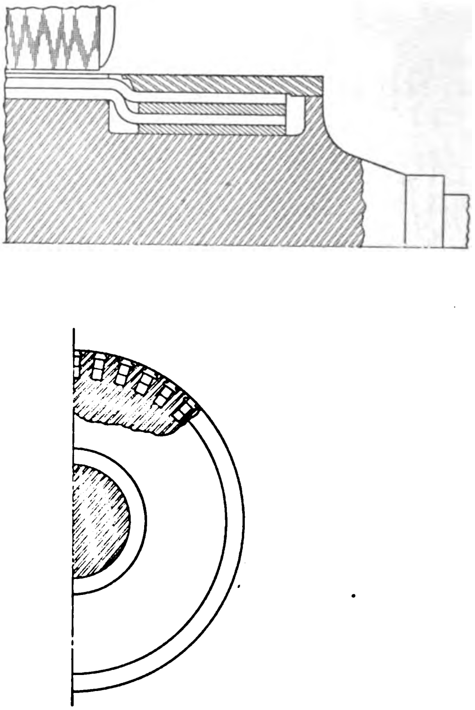

FIG. 9.—TYPICAL CONSTRUCTION FOR A HIGH-SPEED INDUCTION GENERATOR.

factor (or an output of 5250 kv-a.) the cost of the complete synchronous set increases to 129. The two sets (one with an induction generator and the other with a synchronous generator) cost 100 + 129 = 229.

This is just about the cost of a four-pole, 10,000 kw, 100 per cent power factor synchronous turbine-driven set for a speed of 1800 rev. per min.

But certain very distinct advantages are in some cases attained by the use of two 5000-kw. sets in place of a single 10,000-kw. set when the capital outlay is as low for the two 5000-kw. sets as for the single 10,000-kw. set. Thus suppose we have a station equipped with three synchronous and three induction generators, each of the six generators having a capacity for 5000 kw. and the synchronous generators having the slight excess capacity required for exciting the induction generators. When the load does not exceed 5000 kw., the station can be operated with only one generator and this will be of the synchronous type. It will have better economy than a 10,000-kw. set operated at less than half load. When the load is increased to between 5000 and 10,000 kw., one of the induction sets will be thrown on and will run up without requiring synchronizing. When the load exceeds 10,000 kw. but is less than 15,000 kw., a second induction generator will be put in circuit and the two induction generators will be excited by a single synchronous generator. Owing to their higher speed (3600 as against 1800 rev. per min.), the induction generators will have a slightly lower steam consumption than the synchronous generators and hence it will be in the interests of economy (and also of simplicity in operation) to have in circuit at any time a maximum of capacity in induction sets and a minimum of capacity in synchronous sets. In fact, of two alternative layouts for a generating station to supply a given load, two 5000-kw. synchronous and three 5000-kw. induction sets would usually be the practical equivalent (as regards adequate provision for spare plant), of three 10,000-kw. synchronous sets. The capital cost would be:

Five 5000-kw. sets $3 \times 100 + 2 \times 129 = 558$.
Three 10,000-kw. sets $3 \times 220 = 660$

The initial outlay for generating sets would thus be considerably greater in the latter case and there would be no compensating advantage in the matter of lower steam consumption, but rather the reverse. Furthermore the outlay for switch gear and controlling apparatus would be no greater in the first instance, owing to the greater simplicity in operating induction generators. A much smaller aggregate capacity of exciter sets would be required for the first proposition. But this superiority of the first proposition only holds for a system consuming electricity of unity power factor, or for a system requiring a leading current, as, for instance, a system in which all the electricity from the generating station is delivered to synchronous substations. To emphasize this point let us carry through an estimate for a case where the power factor of the system is 0.80. Let us consider that there is one synchronous generator and one induction generator. The former has four poles, runs at 1800 rev. per min. and has an out-put of 5000-kw. The latter has two poles, runs at 3600 rev. per min. and has an output of 5000 kw. The induction generator cannot supply the lagging component, consequently the synchronous generator must supply twice as great a lagging component as would be the case were both generators

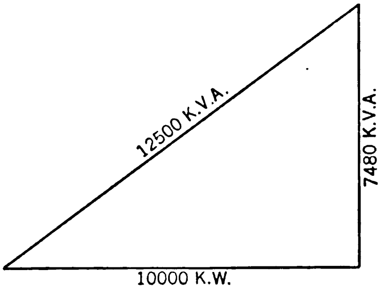

Fig. 10.—Vector Diagram of the Energy Component, Wattless Component and Resultant kv-a, for a System Consuming 10,000 kw. at a Power Factor of 0.80.

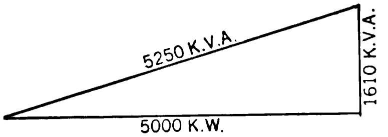

Fig. 11.—Vector Diagram of the Energy Component, Wattless Component and Resultant kv-a- in the Windings of a 5000- kw. Induction Generator.

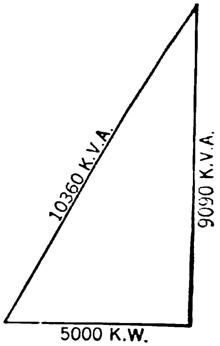

Fig. 12.—Vector Diagram of the Energy Component, Wattless Component and Resultant kv-a. in the Windings of a 5000-kw. Synchronous Generator Operating in Parallel with a 5000- kw. Induction Generator in Supplying 10,000 kw. at a Power Factor of 0.80.

of the synchronous type. Indeed the synchronous generator must also supply the magnetizing current for the induction generator. The system supplied by the two generators consumes 10,000 kw. at 0.80 power factor or $\left(\frac{10,000}{0.80} = \right)$ 12,500 kv-a. The diagram conforming to these conditions is shown in Fig. 10 and it is seen that the wattless component of the electricity consumed by the system is 7480 kv-a.

The induction generator only supplies 5000 kw. and is not competent to supply any part of the wattless component. Consequently this entire wattless component of 7480 kv-a. must be carried by the synchronous generator in addition to an energy component of 5000 kw. (its half of the 10,000 kw.). Furthermore the synchronous generator must supply the magnetizing kilovolt-amperes for the induction generator. This is seen from the diagram in Fig. 11 to amount to 1610 kv-a. which brings the total wattless component of the load on the synchronous generator up to 7480 + 1610 = 9090 kv-a.

The total capacity required of the synchronous generator is seen from the diagram in Fig. 12 to be 10,360 kv-a.

Its power factor is $\frac{5000}{10,360} = 0.48$.

From similar calculations at other power factors and from some preliminary cost estimates, the following table has been derived.

Power factor of the system supplied....	1.00	0.90	0.80	0.70
Power factor 3600-rev. per min. ind. gen.	0.95	0.95	0.95	0.95
Power factor 1800-rev. per min. syn. gen.	0.95	0.61	0.48	0.39
Kv-a. capacity of 1800-rev. per min. syn. gen..............................	5250	8200	10,400	12,900
Excitation of syn. gen. (in kw.)........	26	42	50	60
Initial cost of syn. gen. set (*i.e.*, including turbine)............................	129	155	175	196
Initial cost of ind. gen set (*i.e.*, including turbine)	100	100	100	100
Total for the two gen. sets.............	229	255	275	296
Cost for one 1800-rev. per min. syn. gen. set of 10,000 kw. rated output at the power factor of the system..........	220	—	240	—

This table has been deduced and included in order to direct into right channels the exploitation ofthe induction generator. While the simplicity of the induction generator and various other features relating to its operation to which attention will be directed at a later section of this paper, indicate forit an appropriate field other than in systems of unity power factor, nevertheless, it is hardly possible to emphasize too strongly the rapid increase in the burden which a decreasing power factor throws on the synchronous generator in a system supplied jointly by the two types of generating sets.

A study has been made of a 30,000-kw. turbine-driven set in which the high pressure stages are incorporated in a 15,000-kw. bipolar 1500-rev. per min, 25-cycle set of the induction type, the low pressure stages being incorporated in a 15,000-kw four-pole, 750-rev. per min., 25-cycle set of the synchronous type. Such a plan gives a self-contained set and permits of very material advantages, foremost amongst which are those relating to obtaining a high thermodynamic efficiency. The estimates indicate that such a set would yield a very fine performance. The general arrangement of this 30,000-kw. set is indicated in Fig. 13.

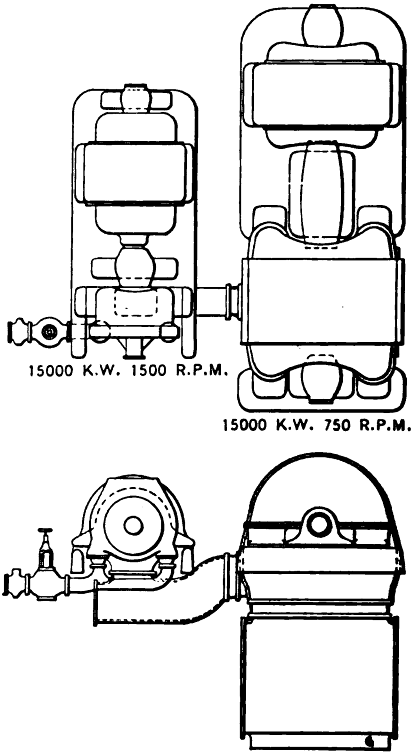

Fig. 13.—General Arrangement of a 30,000-kw. Turbo-Generator Comprising Two Components.

These components consist of a 15,000-kw., 1500-rev. per min., induction set and a 15,000-kw., 750 rev. per min., synchronous set.

THE DESIGN OF INDUCTION GENERATORS

Were it not for the fairly small radial depth of the air gap the design of the stator would not differ in any material respect from that appropriate for a synchronous generator of the same rating as regards output, speed and periodicity. But the appropriate radial depth for the air gap is a matter of only a few *millimeters* in the case of induction generators instead of a matter of a few *centimeters* which is appropriate for large synchronous generators. In Fig. 14 is given a curve showing the variation in power factor for varying depths of air gap for a 2500-kv-a., 3600-rev. per min. induction generator.

The small air gap precludes the employment of wide open stator slots, for with such a construction, the surface of the rotor is the seat of serious losses. These losses consist both of eddy current losses and of hysteresis losses and correspond to a frequency depending upon the number of stator slots and speed. Thus in a 25-cycle, four-pole machine running at 750 rev. per min., and having 72 stator slots, the periodicity of the magnetic pulsations occasioned at the surface of the rotor as it revolves past the stator teeth is $\frac{750}{60} \times 72 = 900$ cycles per second.

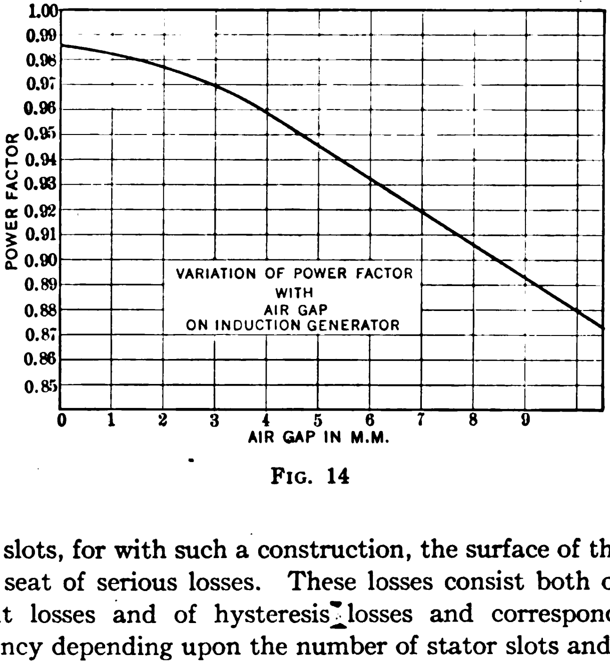

FIG. 14

The losses are due to the local alterations in the reluctance of the magnetic circuit followed by the lines of self-induction of the stator winding. Consequently while the losses are of but little consequence at no-load (since the current in the stator winding is then merely the magnetizing current), the losses at rated load would, with wide open stator slots, be very considerable. Obviously then, the stator slots should be closed, (or, at any rate, overhung), so that the flux of self-induction of the stator winding shall not cross over into the rotor in any considerable quantity. Furthermore it is important to keep down to a reasonably small value, the magnetomotive force corresponding to the stator conductors in a single slot when they are carrying full load current, for the greater the magnetomotive force, the greater will be the amplitude of the disturbances giving rise to the parasitic losses. Thus in an induction generator it is much more essential than it is in a synchronous generator, to subdivide the winding amongst many small slots instead of concentrating it in a few large slots.

Similar considerations should be observed in the design of the rotor. The rotor conductors are arranged, one per slot, in closed slots. If the magnetomotive force of each rotor conductor is sufficiently great, serious parasitic losses will be occasioned in the stator teeth. The periodicities of these disturbances in the stator due to the rotor will be proportional to the speed and to the number of rotor slots. Thus in 750-rev. per min., four-pole, 25-cycle induction generator with 60 rotor slots, the periodicity of the magnetic disturbances will be

$$\frac{750}{60} \times 60 = 750 \text{ cycles per second.}$$

Consequently it is important that both in the stator and in the rotor, the conductors be well distributed. These considerations indicate that the European practice of employing hand winding in closed slots has a greater justification for induction generators than for synchronous generators. But if it is preferred to employ form-wound stator coils, it is feasible, after the windings have been placed in the slots, to close the slots by the insertion of magnetic wedges. Such wedges have been developed and employed experimentally on one of the 11,000-volt, four-pole, 25-cycle, 750-rev. per min., 7500-kw. induction generators built for the Interborough Rapid Transit Company's 59th Street station.

Tests of considerable interest were made on this generator, both with laminated magnetic wedges and with wooden wedges. There are five 7500-kw. induction-generator sets in the station, driven by turbines supplied with exhaust steam from five 7500-kw. low-speed reciprocating sets. All the induction generators were originally equipped with wooden wedges and the radial depth of the air gap was 0.15 in. The arrangement of the stator and rotor slots is shown in Fig. 15. To study the magnetic disturbances, occurring with increasing load, exploring coils were wound around the tips of four adjacent stator teeth. It was determined to supply four exploring coils for the reason that the machine had a fractional-pitch winding and the conditions differ to a certain extent in different teeth. The relation of the location of the exploring coils to the windings of the three phases is indicated in Fig. 16. Each exploring coil consists of a single

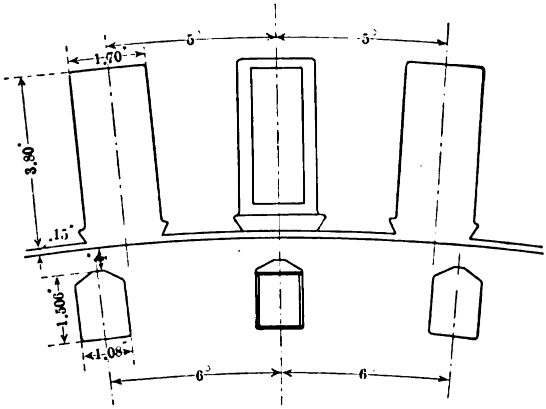

FIG. 15.—ARRANGEMENT OF STATOR AND ROTOR SLOTS OF A 7500-KW. INDUCTION GENERATOR.

turn of number 18 B. & S. wire. Oscillograph records were taken at the terminals of these exploring coils and served to disclose the presence and amplitude of the ripples superposed upon the main flux. The amplitude of these ripples was very considerable, and their periodicity was 750 cycles per second, corresponding to 60 rotor slots and the turbine's speed, which was 750 rev. per min. It must be observed that these ripples were present notwithstanding that the rotor conductors were located in holes, the upper surfaces of which were 12 mm. (0.5 in.) below the surface of the rotor. It is fair to conclude that had a similar study been made by means of an exploring coil wound around a rotor tooth, we should have verified the presence of 900-cycle ripples in the rotor teeth. The amplitude of the ripples increased with the load. This is interestingly shown in the records in Figs. 17 and 18. Those at the left relate to the machine when the stator coils were retained by wooden wedges and those at the right were obtained from tests made after replacing the wooden wedges by a set of experimental laminated magnetic wedges. Both sets of records have been re-drawn to bring them to the same scale. In Fig. 19 are plotted two curves showing the magnitude of the ripples in the stator as a function of the load, for a machine with wooden wedges and a 3.8 mm. (0.15 in.) air gap, and also for this machine when re-fitted with the experimental magnetic wedges and with the air gap increased to 6.4 mm. (0.25 in.). This increase in the air gap was accomplished by turning down the rotor. The heating tests on the machine did not indicate, however, that the change in the air gap materially affected the losses. The difference in the magnitude of the ripples is correctly ascribed to the substitution of the magnetic wedges.

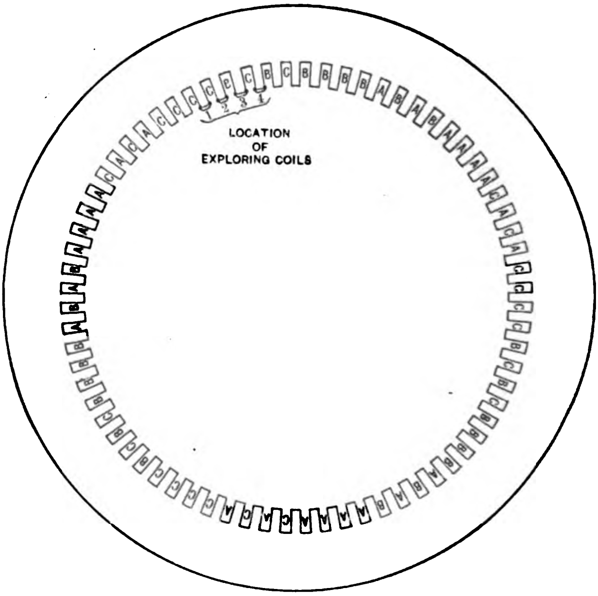

FIG. 16.—LOCATION OF EXPLORING COILS FOR INVESTIGATING RIPPLES IN STATOR TEETH.

It must be especially noted that these experimental magnetic wedges were fitted to the *stator* slots for the express purpose of

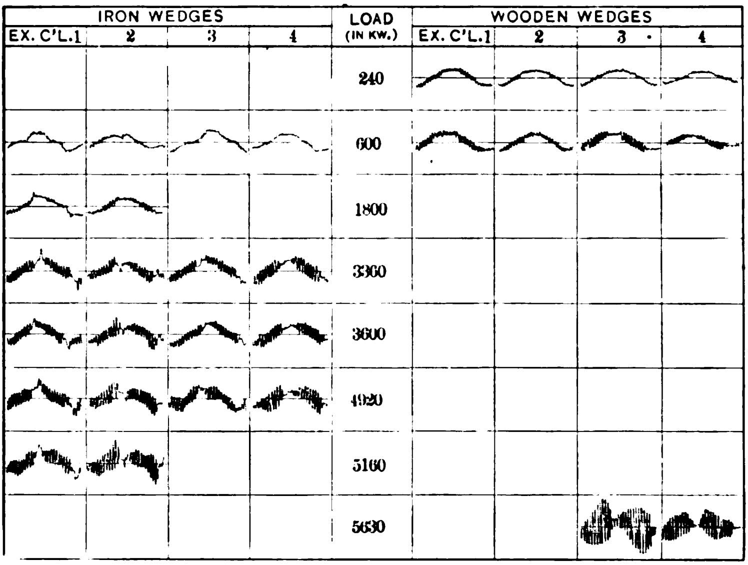

FIG. 17.—TOOTH RIPPLES ON 7500-KW. INDUCTION GENERATORS.

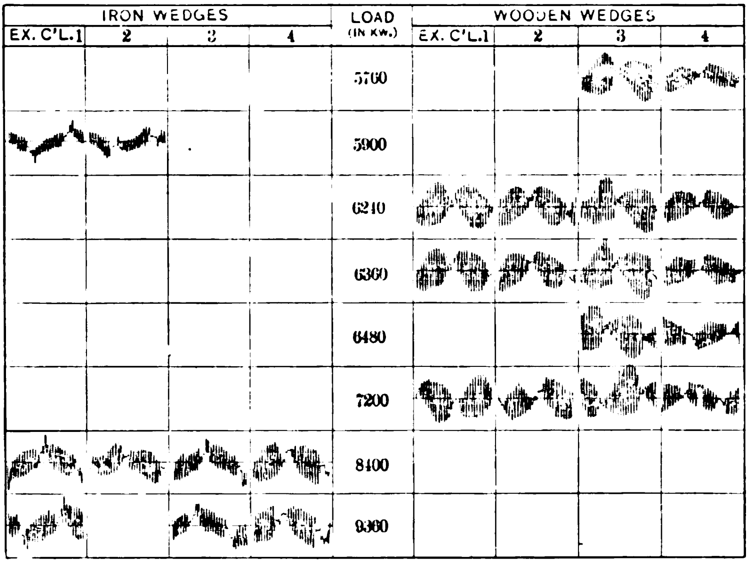

FIG. 18.—TOOTH RIPPLES ON 7500-KW. INDUCTION GENERATORS.

studying, by temperature measurements, the decrease in the losses in the *rotor* due to the 900-cycle ripples *occasioned in the rotor* by the large concentrated magnetomotive forces in the *stator* slots. The slight diminution shown in Figs. 17, 18 and 19 to have been occasioned in the amplitude of the 720-cycle ripples in the stator teeth was only an incidental gain, superposed upon the great diminution in the amplitude of the ripples which is brought about by embedding the rotor conductors 12 mm. (0.5 in.) below the rotor surface. So far as decrease in the losses in the stator is concerned, the addition of these experimental magnetic wedges is more or less analogous to deepening by a few more millimeters the location of the rotor bars. If it had been practicable to provide exploring coils around the rotor teeth, oscillograph records would assuredly have disclosed a diminution in the 900-cycle ripples in the rotor, in a ratio out of all proportion greater than the relatively slight diminution observed in the 720-cycle ripples in the stator as shown in Figs. 16, 17 and 18.

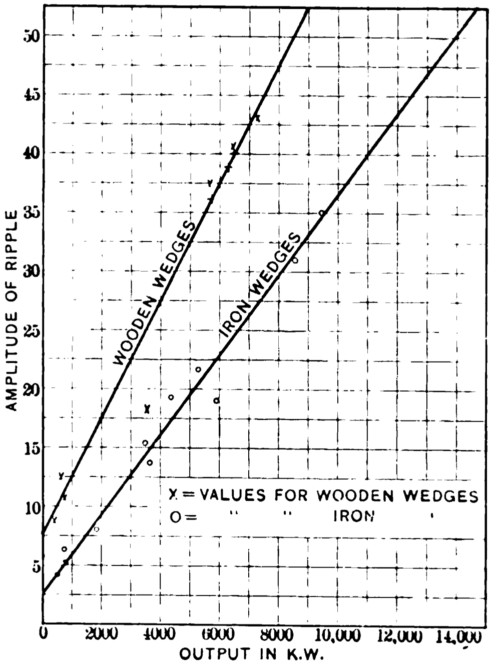

FIG. 19.—CURVES SHOWING DIMINUTION IN AMPLITUDE OF RIPPLES IN STATOR TEETH WHEN EXPERIMENTAL MAGNETIC WEDGES WERE SUBSTITUTED FOR WOODEN WEDGES.

No Load Losses

After eliminating the friction of the turbine wheels the bearing friction and generator windage was ascertained to amount to 120 kw. The core loss at no load was ascertained to be 175 kw. with the wooden-wedge construction and 135 kw. with the magnetic-wedge construction.

In each case the machine was cooled by the circulation through it of 30,000 cu. ft. of air per minute.

The ultimate rise of temperature at no load as observed by thermometric readings of the temperature of the outgoing air varied considerably in various tests, but may, for the magnetic-wedge construction, be taken as about 13.5 deg. cent.

The internal losses to which the temperature rise of the air is due, aggregated

bearing friction and windage + core loss = 120 + 135 = 255 kw.

The loss per degree rise of temperature was thus

$$\frac{255}{13.5} = 18.9 \text{ kw.}$$

The loss per cubic foot of air per degree rise, is

$$\frac{18{,}900}{60 \times 30{,}000} = 0.0105 \text{ watt-hours.}$$

Load Tests

When tested at the rated load of 7500 kw. the temperature rise of the outlet air was

25 deg cent. with wooden wedges.
20 deg. cent. with magnetic wedges.

Employing for the estimation of the total losses at rated load the value of 18.9 kw. loss per degree rise, we obtain

Total internal losses at rated load with wooden wedges = 25 × 18.9 = 473 kw.

Total internal losses at rated load with magnetic wedges = 20 × 18.9 = 378 kw.

From the resistance of the stator windings and of the squirrel cage, the legitimate I^2R losses are ascertained to be

Full load I^2R loss in stator windings, 18 kw.

Full load I^2R loss in squirrel cage windings, 30 kw.

Thus the legitimate losses at rated load are made up as follows:

Bearing and windage losses	120 kw.
Stator core loss	135 "
Stator I^2R loss	18 "
Rotor I^2R loss	30 "
Allowance for legitimate core loss in rotor	5 "
Total of legitimate losses at rated load	308 "

Consequently

Parasitic losses at rated load when employing wooden wedges = 473 — 308 = 165 kw.

Parasitic losses at rated load when employing magnetic wedges = 378 — 308 = 70 kw.

The results indicate that even with the magnetic wedges the parasitic losses, at rated load, still amount to 70 kw. The greater part of this 70 kw. could be eliminated in a design employing a lower magnetomotive per slot. In these machines there were 11 conductors per slot and at rated load the current in each conductor amounted to about 210 amperes. Consequently at rated load the crest value of the magnetomotive concentrated in a single stator slot is no less than $11 \times 210 \times \sqrt{2} = 3270$ ampere conductors.

In the rotor there are only 60 slots, each containing one conductor and at rated load the current in each conductor is about 2700 amperes. Thus the magnetomotive force per rotor slot has a crest value of $2700 \times \sqrt{2} = 3820$ ampere conductors. These values represent undesirably great concentration of magnetomotive force and in spite of employing closed slots, will occasion such great periodic fluctuations in the flux distribution as to give rise to very considerable parasitic losses. The remedy obviously lies in employing a greater multiplicity of slots and less magnetomotive force per slot. This again emphasizes that in the case of induction generators it is of greater advantage even than in synchronous generators to wind the stator for relatively low pressure and employ compensators or transformers to step up to the line pressure.

It appears the most reasonable plan to advocate any new type of apparatus for that range of work for which it is most eminently appropriate. Induction generators are the more appropriate and have the more favorable characteristics, the higher the speed and the greater the rated output. It should furthermore be observed that it is precisely for this range of work (extra-high speed in large capacities) that very grave limitations are met with in the design of synchronous generators. Yet this is an ideal rating for an induction generator, for it would require but a very small magnetizing current and would have a rotor of ideal mechanical and electrical simplicity whereas a bipolar rotating field for excitation by direct current presents, in such a size and for such a speed, thermal and mechanical problems of a very serious nature. Consequently we consider that the most rational plan is to introduce induction generators at this upper end of the line and let the future decide in how far they will win for themselves a useful field at lower speeds and for smaller capacities. Personally, we are of the opinion that the inherent merits of induction generators will secure for them a very considerable field for usefulness which is now fairly satisfactorily occupied by synchronous generators. But the place to first introduce them is where the synchronous design either fails to be feasible or involves very disadvantageous features, and where, moreover, the induction design displays its best characteristics.

In large sizes of high speed induction generators, it may be preferable to use a rotor in which the shaft and core are cut from a solid piece. Such a construction is not in any way objectionable for the rotor of an induction generator, for we can design it with a slip at rated load of, say, two-tenths of 1 per cent. This corresponds to a rotor periodicity of only ($0.002 \times 60 =$) 0.12 of a cycle per second, or 7.2 cycles per minute and under such conditions there is no necessity for employing a laminated core.

The necessity for employing in induction generators a very small air gap renders it more important than in synchronous generators that the magnetomotive force per slot (expressed in ampere conductors at rated load) should be small. This requires the subdivision of the winding amongst a larger number of slots per pole than would be sufficient for a synchronous machine of the same rating. The subdivision of the winding in many slots increases the desirability of employing a low pressure and renders it especially advantageous to adopt the plan of stepping-up to the line pressure through a compensator. The most economical ratio of transformation for the compensator is 2 : 1. Consequently if an induction generator is to supply a 12,000-volt system, it should be wound for 6000 volts and should supply the system through a 2 : 1 compensator.

One of the important uses for the induction generator is the furnishing of additional capacity in stations which are at present equipped with synchronous generators. In general, the slower the speed the more adaptable is the synchronous generator for use with induction generators. This is due to the fact that both field and armature can furnish, without dangerous heating, the extra current necessary for excitation. In engine-driven and slow-speed, water-wheel-driven generators, built from eight to twelve years ago, the requirements of voltage regulation were such that the temperatures were low, consequently, such machines can easily perform the extra duty of exciting the induction generator. When the power factor of the system is near 1.00 the extra duty will not usually involve changes in the exciter or field winding. In other cases where the exciter voltage would be insufficient to give the extra field current the remedy lies in exciters of higher voltage or a change in the field winding.

In power houses of the above class there is usually sufficient space for the installation of a high speed steam turbine unit without the necessity of enlarging the station. Since the induction generator is essentially a high-speed machine its use in such a station is an inexpensive means of greatly increasing the output of the station.

A comparative study of two designs, one for a 2500-kw. synchronous generator, and the other for a 2500-kw. induction generator, both supplying a system at unity power factor has led to results from which the following table of data has been compiled:

	Synchronous generator	Induction generator
Core loss	30 kw.	30 kw.
Primary I^2R loss	9.5 "	10.5 "
Secondary I^2R loss	6.5 "	2.8 "
Windage	35 "	35 "
Total loss, excluding friction of bearings	81 "	78.3 "
Efficiency, excluding friction of bearings	96.9 per cent	97 per cent
Per cent slip at rated load	0.0 per cent	0.11 per cent

This indicates that the efficiency is practically the same for either type of generator. The ventilation of the two machines would be radically different. The large air gap of the synchronous generator permits of a design in which the air passes axially along the gap and out through air ducts normal to the axis of the shaft. The small air gap of the induction generator necessitates a different method. For this machine we should provide a single large air duct in the center of the armature core normal to the axis of the shaft and a number of axial ducts leading from this to the ends of the machine. These would be supplemented by the air gap and by small passages at the outer surface of the core. By this method less cooling surface is required since the temperature gradient ***parallel***, is only a fraction of that ***normal*** to the plane of the laminations. In both machines the movement of air would be produced by fans on the ends of the rotor.

In Europe several other methods have been devised whereby it is unnecessary to pass the air axially along the air gap. By one method the air from the fans on the ends of the rotor is passed to a chamber at the external surface of the armature core. This chamber opens into air ducts in a plane at right angles to the shaft. Suitably shaped space blocks lead the air in a tangential direction to axial ducts just back of the stator slots. The air then flows axially through one section, to the next air duct and then outwardly in a tangential direction to a chamber at the outer surface of the core. This chamber is adjacent to the one first mentioned and leads to the exit from the stator frame. Looking along the axis of the shaft the air flows in a V-shaped

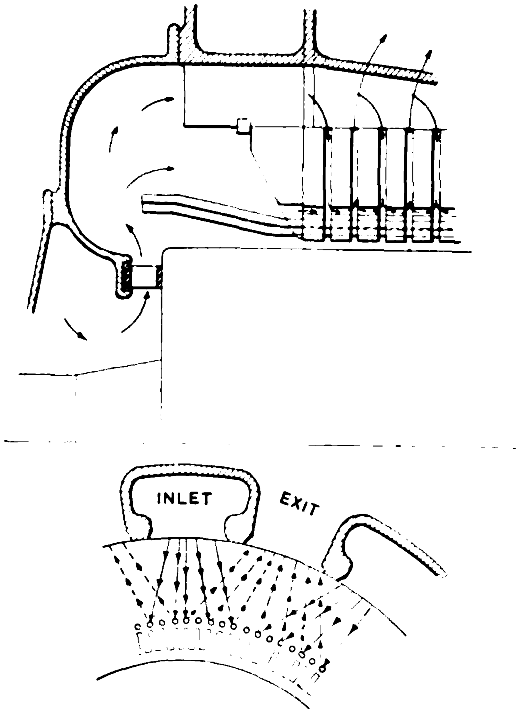

FIG. 20.—A METHOD FOR VENTILATING ALTERNATORS.

path the axial duct back of the stator slots being at the apex. Thus the two legs of the V are separated axially by a single armature section. The method is illustrated diagrammatically in Fig. 20.

Still another method which is independent of the air gap consists in dividing the stator frame into cylindrical chambers placed side by side. The air is forced into a chamber from which it first passes radially toward the shaft, then axially to adjacent air ducts, and finally outwardly to a chamber alongside the one first mentioned. This last chamber communicates with the outer air. The method is illustrated in Fig. 21.

There are several other methods more or less similar to the above, any of which can be applied to the induction generator.

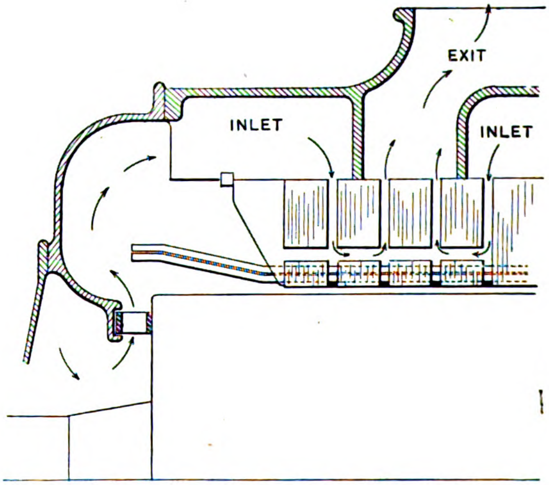

Fig. 21.—A Method for Ventilating Alternators.

On account of the small air gap of induction generators the value of the critical speed of vibration is especially important. If possible the critical speed should be at least 10 per cent above normal. If other important considerations require employing a critical speed below normal it should be *considerably* below, care being taken that the second critical speed is also removed from the normal, preferably above it. With such a design the rotor should have a very careful running balance before it is placed in the machine. A damping bearing could be used to prevent the rubbing of the rotor and stator if for any reason the machine should be subjected to abnormal vibration.

It should be noted that in cases where the critical speed must be below the normal speed, the air gap cannot be so small as would be preferred from the standpoint of minimizing the magnetizing current. A consideration tending to the use of a shaft with a critical speed below the normal running speed relates to the lower peripheral speed thereby obtained at the bearings.

Let us now turn our attention to the application of the induction generator in instances where its superiority rests upon its practically automatic operation.

The necessity for the constant presence of attendants can be eliminated. This is of importance in such cases as districts where there are many small water powers. At each water power a generating installation should be provided. The output from each of these generating stations should be delivered into a transmission line feeding to a collecting station where all these contributions should be collected and delivered to a main transmission line. In each generating station should be installed an induction generator driven by a waterwheel. The excitation should be provided by synchronous condensers at the collecting station. It would often be desirable to locate the collecting station at a water power and install there one or two synchronous generators driven by water wheels. It would not be necessary to have attendants at the small induction generator stations. Occasional inspection would suffice. The induction generator would be connected directly to the line and the energy delivered from the water wheel would be transformed by the induction generator into electricity and would in this form be received at the collecting station. If the line should, from any cause, become open-circuited, the water wheel would run up toward double speed and either this should be provided for in the mechanical design or else an automatic regulator should be provided.

We wish in conclusion to call attention to the appropriateness of the induction type of generator when the supply must be in the single-phase form. It is well understood that in order to neutralize the pulsating armature reaction in a single-phase machine it is necessary to provide damping windings in the pole faces. It is usually found preferable that these damping windings should take the form of an ordinary squirrel-cage structure. Roughly, but with sufficient exactness for practical purposes, we may say that if the aggregate cross-section provided by the face conductors of the squirrel cage equals the aggregate cross-section of the stator conductors, then the loss incurred in neutralizing the pulsations of the stator current, is about equal in amount to the stator I^2R loss. If the cross-section of the rotor conductors is half this value then the loss in the neutralizing winding will be twice the stator I^2R loss and, conversely, if the cross-section provided in the neutralizing winding is twice that of the stator conductors then the loss in the neutralizing winding will be only half the stator I^2R loss. But in a synchronous generator there is rarely room to place a squirrel cage winding of greater aggregate cross-section than that of the stator winding, for we are usually crowded for space even for the main field winding. Consequently the losses in the single-phase generator include in addition to those in a three-phase generator, a loss in the neutralizing winding and this additional loss is usually of about the same magnitude as the stator I^2R loss. This pulls down the efficiency very decidedly and leads to a very discreditable result in that the single-phase machine not alone has only about half the capacity of the same machine when providing three-phase electricity, but it also has a much lower efficiency.

But in an induction generator the squirrel cage winding is the *only* winding on the rotor and it is in any case exceedingly liberally proportioned in order that the rotor I^2R loss shall be a minimum. This same quirrel cage will serve to very effectively neutralize the pulsating armature reaction and it would appear that the resultant I^2R loss in the squirrel cage will be very small indeed. Thus although in employing an induction design for the single-phase generator, we still find it necessary to forego utilizing more than two-thirds of the stator winding, and must consequently rate the machine down by some 33 per cent below its three-phase rating, we shall have the advantage that so far as relates to the rotor, we only require the regular squirrel-cage winding and this will not be the seat of a materially greater loss than when the machine is employed for providing three-phase current. The stators would be supplied with normal three-phase windings and all three phases of these windings would receive magnetizing current from the corresponding windings of the synchronous generators. Only two of the phases would be employed for providing the single-phase current.

The tests of the 7500-kilowatt induction generators of the Interborough Rapid Transit Company, some results of which have been incorporated in this paper, where to a large extent carried out by Mr. H. G. Stott and Mr. H. H. Barnes, to whom the writers wish to offer their hearty thanks for permission to employ this material. They also wish to express their thanks to Messrs. G. C. Hall and G. I. Rhodes of Mr. Stotts engineering staff, and Mr. T. F. Barton of Mr. Barnes' engineering staff, and to Mr. L. T. Robinson, for their cordial cooperation.

In conclusion is added the following brief bibliography of some leading contributions to the literature of the subject.

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CHARACTERISTICS AND APPLICATIONS OF VIBRATION GALVANOMETERS

BY FRANK WENNER

In the vibration galvanometer we have a type of synchronous motor which is distinctly different from all the ordinary types of dynamo electric machines. Further it does not have any of the characteristics of any of the ordinary galvanometers and except for the fact that it is used in the detection or measurement of small currents and voltages, it should not be called a galvanometer. In galvanometers, except when used in the measurement of transient currents or quantity of electricity, the moving system is displaced until we have an equality of static couples acting on it. In the vibration galvanometer the equilibrium condition is an equality between integral values of the product of the current and generated voltage and the mechanical power dissipated in various ways as in ordinary electric motors when operated without a load. It therefore behaves more like an electric motor than like a galvanometer. Further, since it is used only with alternating currents and operates in synchronism with the current it must necessarily have some of the characteristics of a synchronous motor. As a motor the efficiency of conversion was found in a particular case to be as high as 97½ per cent while the power required to maintain an easily discernable amplitude of vibration was of the order of 10^{-11} watts. One of the large turbo-generators would therefore furnish the power necessary to operate a thousand-million-billion such machines.

While the vibration galvanometer will probably never be used in the ordinary way for driving other machines yet it is of considerable interest from a theoretical standpoint and possesses certain characteristics which make it a most valuable instrument for use in a large number of alternating-current measurements.

A number of different forms of galvanometers have been and are being used. One form is very similar to an oscillograph except that in general the period is longer and the oil for damping is omitted. Another form is very similar to the D'Arsonval galvanometers of the marine type except that the coil is narrower and the suspensions tighter. In all cases provision is made for changing the period of the moving system. This is usually done by changing the length or tension of the suspensions. Where a large range in frequency is desired the suspensions are often made bifilar.

Passing an alternating current through the coil causes it to vibrate back and forth past its equilibrium position, hence the name vibration galvanometer. The amplitude of the vibration, which is a measure of the current, is ordinarily determined by observing the broadening of a line image as seen in a small mirror attached to the moving system. As regularly used in the detection or measurement of current or voltage the natural or free frequency of the moving system is made to correspond with the frequency of the alternating current to be detected. As a result the amplitude of the vibration is much larger than it would be under almost any other condition.

The sensitivity is large only to currents of the frequency to which the moving system of the galvanometer is tuned. It is therefore possible to use currents of almost any wave form, even in those null methods in which an exact balance can be obtained only with a current free from all higher harmonics. In all such measurements we may make our observations and calculations just as if we were using current having a sine wave form since the galvanometer responds only very feebly to the 3rd, 5th and higher harmonic components. It is this characteristic combined with its extremely high sensitivity at low frequencies which makes the vibration galvanometer a most valuable instrument in various kinds of alternating current measurements.

Before we can make such progress in the design of an instrument or machine it is necessary that we know definitely the relation between its various constants. In some cases this knowledge is necessary before we can even use a well designed and constructed instrument or machine to its best advantage. We shall therefore show the relation which exists between the amplitude of the vibration and the impressed voltage in terms of the intrinsic constants of the instrument and of the electric circuit in which it may be used. Since here we have a mechanical and an electrical oscillating system so connected that they must necessarily operate at the same frequency we shall make free use of the analogy existing between such systems. Passing a current through the winding produces a mechanical torque tending to displace the moving system of the galvanometer from its equilibrium position. The torque is proportional to the current and we shall let G be the proportionality factor or the displacement constant. In addition we shall use the following notation, in which vectors are designated by bold faced type and make use of the following well known relations:

IN THE ELECTRICAL SYSTEM	IN THE MECHANICAL SYSTEM
L = inductance	K = inertia constant
r = electrical resistance	D = damping constant or mechanical resistance
C = capacity	U = restoring constant analagous to $1/C$
e' = impressed voltage	$G\mathbf{i}$ = displacing torque
$\mathbf{i}$ = current	s = rate of displacement or angular velocity
q = charge = $\int \mathbf{i}\,\delta t$	ϕ = displacement = $\int s\,\delta t$

$$e' = E'\,\epsilon^{ipt} \tag{1}$$

$$G\mathbf{i} = G\,I\,\epsilon^{ipt} \tag{2}$$

$$\mathbf{i} = I\,\epsilon^{ipt} \tag{3}$$

$$s = S\,\epsilon^{ipt} \tag{4}$$

$$q = Q\,\epsilon^{ipt} \tag{5}$$

$$\phi = \Phi\,\epsilon^{ipt} \tag{6}$$

$$I = \frac{E}{r + i\,(p\;L - 1/C\,p)} \tag{7}$$

$$S = \frac{G\,I}{D + i\,(K\,p - U/p)} \tag{8}$$

or if we let X represent the electrical reactance and M represent the mechanical reactance

$$I = \frac{E'}{r + i\,X} \tag{9}$$

$$S = \frac{G\,I}{D + i\,M} \tag{10}$$

$$Q = \frac{E'}{i\,p\,(r + i\,X)} \tag{11}$$

$$\Phi = \frac{G\,I}{i\,p\,(D + i\,M)} \tag{12}$$

Here E' is the total voltage available for producing current or the sum of the impressed voltage E and generated voltage E_g.

The voltage generated by the relative motion of the magnet and winding is proportional to the amplitude and in quadrature with the vibration. It is also proportional to the frequency and proportional to the displacement constant and it is easily shown that

$$E_g = -\,i\,p\,G\,\Phi \tag{13}$$

therefore

$$I = \frac{E - i\,p\,G\,\Phi}{r + i\,X} \tag{14}$$

This value of I substituted in equation (**12**) gives

$$\Phi = \frac{G\,E}{p\,[(-r\,M - D\,X) + i\,(Dr - M\,X + G^2)]} \tag{15}$$

or

$$\Phi = \frac{G\,E}{p\,\sqrt{(-r\,M - D\,X)^2 + (Dr - M\,X + G^2)^2}} \tag{16}$$

or

$$\phi = \frac{G\,E\,\epsilon^{i\,(pt + \alpha)}}{p\,\sqrt{(-r\,M - D\,X)^2 + (Dr - M\,X + G^2)^2}} \tag{17}$$

where

$$\tan\alpha = \frac{-(Dr - M\,X + G^2)}{M\,r + D\,X} \tag{18}$$

Equation (**16**) gives the relation between the amplitude of the vibration, the impressed voltage, the displacement constant, the frequency, and the other constants of the electric and mechanical systems expressed as resistances and reactances.

Where the instrument is to be used in precise measurements we usually desire as high a sensitivity as can conveniently be obtained, *i.e.* we wish as large an amplitude of the vibrations for a given small impressed voltage as we can conveniently get.

An inspection of equation (**16**) does not at once suggest the relations which should be made to exist between the various quantities D, r, M, X, and G to give the best sensitivity. Since power is absorbed or converted into heat proportional both to D and to r the most natural beginning is to make both small. The mechanical resistance or damping constant D is a definite constant of the galvanometer and as we shall see later one of the most important points to be looked to both in the design and the construction is to make this constant as small as possible.

The electrical resistance r is the total resistance of the circuit in which the galvanometer is used. As the resistance of a part of this circuit is usually fixed from other considerations the particular value of the resistance of the galvanometer is of little importance providing it is less than say $\frac{1}{4}$ the total resistance of the circuit.

As vibration galvanometers are usually constructed provision is made for varying the free period of the moving system so that the mechanical reactance can be adjusted to zero for any frequency in the range over which it is expected that the galvanometer will be used. The electrical reactance is usually very small in comparison with the electrical resistance. It can however, be varied by placing capacity or inductance in series with the winding of the galvanometer.

If the galvanometer is so constructed that the displacement constant G can be varied; and all instruments intended for use in circuits of different resistances should, if a high sensitivity is desired, be so constructed; we can then adjust each or all of the remaining quantities, the electrical reactance X, the mechanical reactance M, and the displacement constant G. If M, is adjusted to zero and if z is small or adjusted to zero it will be seen that the sensitivity is a maximum when

$$G^2 = Dr$$

Under these conditions we have

$$\Phi = \frac{E}{2\,p\,\sqrt{Dr}} \tag{19}$$

or since we observe the total amplitude of the vibration and measure the root mean square value of the voltage

$$\Phi = \frac{E}{p\,\sqrt{2\,Dr}} \tag{20}$$

as has been shown by the author.[1]

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[1] *Bulletin*, Bureau of Standards, Vol. VI, p. 376; reprint 134; 1909.

Under these conditions the generated voltage is half as large as and in direct opposition to the impressed voltage. This we know to be the conditions under which the mechanical power developed is a maximum. This, then is a condition which gives the maximum sensitivity with the particular values of r and D.

Since to get the maximum sensitivity it is only necessary to make such adjustments as will bring the generated voltage in direct opposition to and make it half as large as the impressed voltage it should be possible to bring about this condition by changing any two of the three constants X, M, and G. If these constants are changed one after the other in small steps or continuously it can be shown by differentiation that the sensitivity becomes a maximum for changes

$$\text{of } X, \text{ when } X = \frac{G^2 M}{D^2 + M^2} \tag{21}$$

$$\text{of } M, \text{ when } M = \frac{G^2 X}{r^2 + X^2} \tag{22}$$

$$\text{and of } G, \text{ when } G = \sqrt[4]{(r^2 + X^2)\ (D^2 + M^2)} \tag{23}$$

Since the last of these equations is the product of the other two it follows that if any two of the constants are adjusted so that they simultaneously have their best value the third constant also has its best value or the sensitivity is the maximum attainable. When this adjustment, which is a double one, and in some cases will have to be made by successive approximations, is carried out we have

$$\frac{X}{r} = \frac{M}{D} \tag{24}$$

or the electrical time constant equal to the mechanical time constant

and
$$\frac{r\,G^2}{r^2 + X^2} = D \tag{25}$$

or the electromagnetic damping equal to the mechanical damping. When we have the first of these relations the generated voltage is in direct opposition to the impressed voltage. When we have the second the generated voltage is half as large as the impressed voltage. When we have both relations.

$$\Phi = \frac{E}{2p\sqrt{Dr}} \tag{26}$$

as given above and has been shown recently by Butterworth.[2]

If we express the amplitude of the vibration in terms of the broadening of the line image 1 meter from a mirror attached to the moving system, the voltage in microvolts, the resistance in ohms and the mechanical constants in c.g.s. units then

$$\Phi = \frac{2.0\ E}{f\sqrt{Dr}} \tag{27}$$

when f is the frequency or if v is the sensitivity the ratio of the number representing the amplitude of the vibration to the number representing the voltage

$$V = \frac{2.0}{f\sqrt{Dr}} \tag{28}$$

Since usually it is not practical to place a variable inductance in series with the galvanometer and by adjusting it and the mechanical reactance to bring about the best condition, and since few of the galvanometers now in use are provided with a means for adjusting G we are often obliged to be content with the best condition we can obtain by the adjustment of the free frequency only. If then this adjustment is made and the electrical reactance is small in comparison with the electrical resistance then equation (**16**) takes the form

$$\Phi = \frac{G\,E}{p\,(Dr + G^2)} \tag{29}$$

and these are the relations under the more usual conditions of use.

To the person who is considering using a vibration galvanometer the question as to what sensitivity can readily be obtained is of much more importance than the effect of various constants upon the sensitivity. In this connection we may state that three years ago the author determined the constants of three vibration galvanometers and found the voltage sensitivity in millimeters per microvolt at 100 cycles as follows:

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[2] *Proceedings Phys. Soc.*, London, Vol. XXIV, p. 77, 1912.

0.0014 0.0061 and 0.0075.

Recently Mr. Silsbee of the Bureau of Standards made, according to the suggestions of the author, a new coil for one of the older galvanometers of the D'Arsonval type in fact one of the three just mentioned. With the new coil the voltage sensitivity at 25 cycles is 0.47. The instrument was designed for use in a bridge having a resistance of about one ohm. It has since been found that it will be necessary to increase the resistance in the bridge arrangement so that the total resistance of the galvanometer circuit will be about four ohms. Under these conditions the sensitivity will be 0.28, while if the magnet is strengthened just a little so as to give the best conditions the sensitivity will be 0.40. With the new coil the galvanometer differs in so many ways from the others that the relative merits cannot be represented by figures giving the ratio of the voltage sensitivities which range from 60 to 300. It cannot be used at a frequency of 100 neither can the others be used at a frequency of 25. It was designed to operate at the lower frequency and to be used in connection with a low resistance bridge. When so used its sensitivity is about the same as that of a good direct current D'Arsonval galvanometer designed for and used in connection with a bridge of the same resistance.

We have gone rather fully into the matter of the sensitivity and the adjustments necessary to get the maximum sensitivity attainable with any particular galvanometer when used in any particular circuit. We have done this because the matter is one of considerable importance to many of those working with such instruments and a matter which seems not to be very well understood.

A further consideration of equation (**16**) will bring out other characteristics of the vibration galvanometer. In cases where the electrical reactance is small in comparison with the resistance so that it need not be considered we have

$$\Phi = \frac{G\,E}{p\sqrt{r^2\,M^2 + (Dr + G^2)^2}} \qquad \textbf{(27)}$$

or since $M = pK - Up$ and $U = p_0^2 K$, where p_0 is the free frequency of the moving system,

$$\Phi = \frac{GE}{r\sqrt{K^2(p_0^2 - p^2)^2 + p^2(Dr + G^2)^2/r^2}} \qquad (28)$$

If $p_0 = p$

$$\Phi = \frac{GE}{p_0(Dr + G^2)} \text{ or } V_0 = \frac{G}{p(Dr + G^2)} \qquad (29)$$

If p_0 is very different from p, $K(p_0^2 - p^2)$ is large in comparison with $p(Dr + G^2)$ so we may write

$$\Phi = \frac{GE}{\pm rK(p_0^2 - p^2)} \text{ or } V = \frac{G}{\pm rK(p_0^2 - p^2)} \qquad (30)$$

or we have

$$\frac{V_0}{V} = \pm(f_0 - f^2/f_0)\frac{2\pi Kr}{Dr + G^2}$$

If the galvanometer has an inertia constant of 0.02, a damping constant of 0.01 and a displacement constant of 10,000 (none of which are exceptional values) then

$$\frac{2\pi Kr}{Dr + G^2} = 6.3, \text{ if } r = 100 \text{ ohms } (10^{11} \text{ c.g.s. units})$$

or

$$12.6 \text{ if } r \text{ is large}$$

Then if the fundamental frequency of the voltage is 60 and the instrument is tuned to this frequency a substitution of 60 for f_0 and of 180 and 300 for f gives the ratio of the sensitivity of the instrument to the fundamental as compared with its sensitivity to the 3rd and 5th harmonic as follows:

With 100 ohms	With high resistance
$S_1/S_3 = 3000$	or $= 6000$
$S_1/S_5 = 9000$	or $= 18{,}000$

If the instrument is tuned to the 3rd or 5th harmonic a substitution of 180 and 300 for f_0 and 60 for f gives the ratio of the sensitivity to the harmonics as compared with its sensitivity to the fundamental as follows:

With 100 ohms	With high resistance
$S_3/S_1 = 1000$	or = 2000
$S_5/S_1 = 1650$	or = 3300

It will thus be seen that the galvanometer when tuned to the funamental is (if the resistance of the circuit is 100 ohms or more) at least 3000 times as sensitive to the fundamental as to any of the harmonics. If then the voltage used in testing has a third and higher harmonics amounting to not more than 3 per cent, the accuracy to which a balance may be established cannot be limited by the presence of unbalanced harmonic components of the voltage, unless the accuracy sought is better than 1 in 100,000. It is this characteristic of not responding to the harmonic components of the current passing through it together with its high sensitivity to the fundamental component both of the voltage and current which has led to the use of the vibration galvanometer in various alternating current measurements.

It will also be seen that where a galvanometer having the constants just considered is tuned to a frequency of three or five times the fundamental and the resistance is high the instrument is 2000 or more times as sensitive to the harmonics as to the fundamental. The instrument can therefore be used to read the harmonic components of the voltage directly from the amplitude of the vibration and it should be possible if the harmonics are small to obtain their values to better than 0.1 per cent of the fundamental. In this method of determining the higher harmonic components of the electromotive force use is made of the mechanical resonating system of the galvanometer instead of an electrical resonating system.

If the frequency of the impressed voltage is varied from below that for which the amplitude of the vibration is a maximum to above this value the angle between the generated and impressed voltage changes by nearly π radians or 180 deg. The change in angle with frequency is largest at the frequency which gives the maximum amplitude. In some cases we have a noticeable change in the phase angle when the frequency changes by only a few hundredths per cent. Considerably below the particular frequency the current lags behind the impressed voltage by nearly $\pi/4$ radians or 45 deg. and considerably above this frequency it leads by about the same amount.

If then the stator windings of a very small two-phase induction motor were connected to the same voltage supply, one through a resistance and the other throuh a large vibration galvanometer we would have, in general, an elliptical rotating field at the stator and the direction of rotation would depend upon whether the frequency of the impressed voltage were above or below that for which the amplitude of the vibration of the galvanometer would be a maximum. It is not at all improbable that such an arrangement might be used to accomplish some particular end in connection with the generation or transmission of electrical power, such for example as the indication or regulation of the frequency.

In engineering work the vibration galvanometer is being used but little. When its characteristics become more widely known and when it becomes known that it is not a delicate instrument various uses will no doubt be found for it.

As a laboratory instrument we may mention that it is being used in the Bureau of Standards in connection with:

The Anderson bridge for the comparison of self inductance with capacity and resistance.

One or more bridge methods for the comparison of self with mutual inductance.

Bridge method for the comparison of the capacities and phase angles of condensers.

Bridge methods for comparing the resistances and time constants of wire resistance standards.

The Thomson bridge method in the comparison of time constants and resistances, to alternating currents, of standards of low resistance.

In the determination of the ratio transformation and the phase angle between primary and secondary voltages and currents of potential and current transformers.

It has also been used in various other precision measurements and the indications are that it will soon be used in still others.

In the National Physical Laboratory in England the vibration galvanometer is also being much used. Of the various applications there we may mention:

The absolute measurement of resistances by a two-phase alternating current method.

The testing of transformer steel using a null method for determining the total losses.

A modified Carey Foster method for comparing self and mutual inductance.

In most laboratories, however, the vibration galvanometer has met with less favor than it deserves.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 25, 1912.

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(*Subject to final revision for the Transactions.*)

THE LAW OF CORONA AND DIELECTRIC STRENGTH OF AIR—II

BY F. W. PEEK, JR.

I. INTRODUCTION AND DISCUSSION OF PART I.*

Part I of this paper* presented at the A. I. E. E. Annual Convention last June gave the results and discussion of extensive investigations of corona formation and loss. These investigations consist of power measurements on a short transmission line under all of the variable conditions of spacing, size of conductor, storms, etc., met with in practise, supplemented with extensive laboratory investigations.

While these formulas made it possible to accurately predetermine the corona characteristics of practical transmission lines over natural temperature and barometric pressure range and commercial frequency range, investigations were continued, and are still being continued, with a view of rationalizing the formulas, and getting at the fundamentals and fundamental mechanism of corona loss. The work of reduction of data obtained to date is still incomplete, and it is also not possible at the present time to include all that has been accomplished.

A considerable mass of new material, however, is given here.

All of this work has been made possible by engineering and test facilities afforded by the Consulting Engineering Department of the General Electric Co. under the general supervision of Dr. C. P. Steinmetz. Thanks are due to Messrs. C. M. Davis, J. L. R. Hayden, C. E. Magnusson, Don F. Smith and C. W. Stone for their active and valuable assistance.

For description of the apparatus and general method of test, see Part I. For convenience of reference the following short summary of equations, etc., is given from Part I.

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* *The Law of Corona and Dielectric Strength of Air*, A. I. E. E. PROCEEDINGS, July, 1911. Hereafter referred to as Part I.

The disruptive critical voltage is

$$e_0 = m_0\, g_0\, r \log_\epsilon \frac{S}{r} \text{ kv. to neutral} \qquad (3)$$

where g_0 is the disruptive gradient of air in kilovolts per cm. at 25 deg. cent. and 76 cm. barometer, and is constant for all sizes of wires, frequencies, etc. If the effective value of g_0 is taken, e_0 is given in effective kilovolts.

Where

r = radius of conductor in cm.
S = distance between conductor and return conductor in cm.,
g_0 = 29.8 kv. per cm. (maximum).
g_0 = 21.1 kv. per cm. (effective).
m_0 = a constant depending upon the condition of the conductor surface.
m_0 = 1 for polished conductors.
m_0 = 0.98 — 0.93 for roughened or weathered wires.
m_0 = 0.89 to 0.83 for cables.

Luminosity of the air surrounding the line conductors does not begin at the disruptive critical voltage e_0, but at a higher voltage e_v, the visual critical voltage.

The visual critical voltage e_v, is much higher for small wires than the disruptive critical voltage, e_0; it is also higher for large wires, but to a lesser extent.

While theoretically no loss of power should occur below the visual voltage, e_v, some loss does occur, due to irregularities of the conductor surface and seems to follow the probability law:

$$p_1 = q\, \epsilon^{-h\,(e_0 - e)^2} \qquad (4)$$

where q is a coefficient depending on the number of spots, and h is a coefficient depending on the size of spots.

Snow, sleet and rain losses seem to be of the same nature but frequently of far greater magnitude.

The visual critical voltage, e_v, is derived from the disruptive gradient, g_0 by the equation

$$e_v = m_v\, g_0\, \delta\, r \left(1 + \frac{0.301}{\sqrt{r}}\right) \log_\epsilon \frac{S}{r} \text{ kv. to neutral} \qquad (5)^*$$

where

$$m_v = m_0 = 1 \text{ to } 0.93 \text{ for wires.}$$

$$m_v = \begin{cases} 0.72 \text{ local corona all along conductor;} \\ 0.82 \text{ decided corona all along conductor} \end{cases} \text{For seven strand cables}$$

If g_0 (maximum) is used, e_v is obtained in maximum kilovolts.

$$g_v = g_0\,\delta\left(1 + \frac{0.301}{\sqrt{r}}\right) \qquad (5a)^*$$

$$p = \frac{k}{\delta}\, f \sqrt{\frac{r}{S}}\left(e - g_0\, m_0\, r\, \delta \log_\epsilon \frac{S}{r}\right)^2 10^{-5} \text{ kw. per km. of single conductor.} \qquad (6)$$

e = effective kilovolts to neutral.
k = 344.
g_0 = 21.1 kv. per cm. (effective).
δ = air density factor = $\frac{3.92\, b}{273 + t}$
δ = 1 at 25 deg. cent. and 76 cm. barometric pressure.
b = barometric pressure cm.
t = temperature deg. cent.
r = radius of conductor, cm.
S = distance between centers of conductors, cm.
f = frequency, cycles per second.

The corona loss is

a. Proportional to the frequency f (over commercial range).

b. Proportional to the square of the excess voltage above the disruptive critical voltage, e_0.

c. Proportional to the square root of the conductor radius r, and inverse proportional to the square root of the conductor distance.

The disruptive critical voltage, e_0, is that voltage at which the disruptive voltage gradient of the air is reached at the conductor surface. Hence, it is

a. Proportional to the conductor radius, r, and the $\log_\epsilon S/r$.

b. Proportional the air density.

c. Depending somewhat on the conditions of the conductor surface as represented by m.

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* Proportional to δ with fair approximation over natural range of barometric pressure and temperature. δ enters also as a function in energy distance. See III.

The effects of various atmospheric conditions and storms on the critical voltage and loss will now be considered. Humidity or "vapor products" have no effect on either the critical voltage or the loss.

Smoke lowers the critical voltage and increases the loss.

Heavy wind has no effect on the loss of critical voltage at ordinary commercial frequencies.

The weather conditions that really count practically and which must be seriously considered in the design of transmission lines are as follows:

Fog lowers the critical voltage and increases the loss.

Sleet on the wires, or falling sleet, lowers the critical voltage and increases the loss. High voltages do not entirely eliminate sleet formation.

Rain storms lower the critical voltage and increase the loss. Snow storms lower the critical voltage and increase the loss. The effect of snow is greater than that of any other weather condition.

II. SUMMARY OF PART II.

1. *Influence of temperature and barometric pressure on* g_v *and* g_0 *over a wide range.*

a. Visual corona starts at a lower voltage if the temperature is increased. Visual corona starts at a lower voltage if the barometric pressure is decreased. That is,

$$e_v = \phi\,(\delta)$$

where δ is the air density factor. If e_v' is the visual critical voltage at $\delta = 1$, over a short range of δ a fair approximation is: $e_v = \delta\, e_v'$.

b. Over a considerable range of air density our experiments show

$$e_v = m_v\, g_0\, \delta\, r \left(1 + \frac{0.301}{\sqrt{\delta\, r}}\right) \log_e \frac{s}{r} \qquad (5')$$

$$g_v = m_v\, g_0\, \delta \left(1 + \frac{0.301}{\sqrt{\delta\, r}}\right) \qquad (5a')$$

c. This means that the *disruptive gradient* varies directly with the air density factor δ, as would be expected and already shown in Part I.

$$g_0 = \delta\, g_0'$$

It also means that the energy storage zone to cause rupture extends

$$0.301 \frac{\sqrt{r}}{\sqrt{\delta}} \text{ cm.}$$

from the conductor surface, and, therefore, g_v does not vary directly with the air density. This is in accordance with the theory of Part I that energy is necessary to cause rupture.

d. The influence of variation of air density is the same over a very wide range whether the variation of air density is caused by change of barometric pressure or temperature.

2. *Influence of Frequency on g_v and g_0.* Between 40 and 100 cycles the influence of frequency on g_v and g_0, if any, is small, and less than the slight changes in wave shape in the testing transformer at different frequencies and which cannot be detected by the oscillograph.

3. *Spark-over and Corona on Polished Parallel Wires or Cylinders.*

a. Where S/r is less than 30 spark-over occurs before corona appears.

b. Where S/r is 30, either spark or corona may occur. This point is very unstable. If corona appears first the spark-over voltage e_s is slightly increased.

c. Where S/r is greater than 30 corona appears at e_v, then spark-over occurs at higher voltage e_s.

d. Above the point of intersection of the e_s and e_v curves plotted with spacing S, e_s follows approximately a straight line through the test range. The g_v curve is a straight line parallel to the S axis. The g_s curve is also very nearly a straight line which intersects the g_v curve at $S/r = 30$, and extended cuts the g axis at $g_0 = 30$ kv. per cm. This seems to be a further check on 30 as the disruptive gradient for air.

e. e_s is less definite than e_v and is greatly influenced by irregularities, dirt, etc. For polished wires and constant spacing, e_s increases with decreasing diameter of the wire. When the conductor surfaces are coated with water, at a given spacing e_s is almost independent of the radius of the wire and approximately follows the needle gap curve. Oil on the conductor surface has a somewhat similar effect. *Water* on the conductor surface always very greatly reduces g_v. *Oil* on the conductor surface reduces g_v to some extent on large conductors, and, by increasing the radius an appreciable per cent raises g_v on small conductors.

f. For the test range it is difficult to determine whether e_s or g_s curve with S more nearly follow a straight line.

1. On the assumption that g_s is in straight line—and this seems the most reasonable assumption—we may write:

$$g_s = 30\left(1 + \frac{0.01}{\sqrt{r}}\,\frac{S}{r}\right) \text{ kv. per cm. maximum}$$

This holds above the triangular point where S/r is greater than 30. When $S/r = 30$ it reduces to the visual corona formula

$$g_s = 30\left(1 + \frac{0.301}{\sqrt{r}}\right) = g_v \text{ kv. per cm. maximum}$$

Experimental points follow this curve well.

2. On the assumption that e_s is a straight line the expression takes the form

$$e_s = 3.4\,S + \frac{S+5}{2.5\sqrt{r}}$$

This curve is based upon the assumption that for a given spacing all sizes of wires would spark-over at the same voltage and when $S/r = 30$ and $g_0 = 30$, if there were no "corona resistance." When r_1 is the total radius of wire and corona, and g_0 = gradient at edge of corona.

This voltage would be at no "corona resistance"

$$3.4\,S$$

However, our experiments show the spark-over varies with size of conductor and the difference is something similar to a "corona drop" expressed by:

$$\frac{S+5}{2.5\sqrt{r}}$$

or the total spark-over voltage is

$$e_s = 3.4\,S + \frac{S+5}{2.5\sqrt{r}} \text{ kv. maximum}$$

Assumption (1) is a closer approximation to experimental values.

The visual corona gradient for a conductor coated with a film of oil is

$$g_v = 19\left(1 + \frac{0.65}{\sqrt{r}}\right) \text{ maximum kv. per cm.}$$

The visual corona gradient for a conductor coated with moisture as by rain or fog is

$$g_v = 9\left(1 + \frac{0.815}{\sqrt{r}}\right) \text{ maximum kv. per cm.}$$

(h.) In concentric cylinders designed for maximum dielectric strength the ratio is not $R/r = \epsilon$, but is modified because g_v is a function of r.

i. Where corona forms before spark in concentric cylinders, as when r is very small compared with R, corona does not extend out to radius x when R/x = critical ratio for metallic cylinders and spark over, but greatly increases the spark over point indicating grading or " corona resistance. "

4. Disruptive gradient g_0—.

That g_0 is constant and is 30 kv. per cm. is indicated by three entirely different methods.

1. By visual corona.
2. By spark-over.
3. By power measurements.

5. *Stroboscopic Study of Corona.* By the use of a stroboscope, a-c. corona discharge was observed on wires and needle points on the negative and positive parts of the wave.

a. To the unaided eye corona discharge often appears to extend completely across between points without arc-over. Examination through a stroboscope shows that the corona extends way out from the positive needle as a bluish white spray. The negative needle appears as a red point.

b. To the unaided eye corona on parallel wires appears as reddish beads more or less evenly spaced, with a bluish white needle-like fringe in between. If the wires are smooth the stroboscope shows the red beads on the negative, and a smooth bluish white glow on the positive. At abrasions or points the positive corona extends way out as very fine bluish needles. Without the stroboscope the eye sees the combination of the positive and negative.

c. In general, the positive discharge appears as fine bluish-white spray or needles, while the negative discharge appears as reddish tufts. The discharge from points always gives the same impression as a stream of water being forced out under pressure from the positive, and gather in at the negative.

6. *Remarks.* Many interesting points are observed and further discussed which cannot be taken up in this summary.

7. *Practical Corona Formulas.* Revised and collected for reference.

Disruptive critical volts (parallel wires)

$$e_0 = 21.1\, m_0\, \delta\, r \log_e \frac{s}{r} \text{ effective kv. to neutral} \qquad (3)$$

Visual critical volts and gradient (parallel wires).

$$e_v = 21.1\, m_v\, \delta\, r \left(1 + \frac{0.301}{\sqrt{\delta\, r}}\right) \log_e \frac{S}{r} \text{ effective kv. to neutral} \qquad (5')$$

$$g_v = 21.1\, \delta \left(1 + \frac{0.301}{\sqrt{\delta\, r}}\right) \text{ effective kv. per cm.} \qquad (5a')$$

Power loss (fair weather)

$$P = \frac{344}{\delta} f \sqrt{\frac{r}{s}}\, (e - e_0)^2\, 10^{-5}$$

$$P = \frac{344}{\delta} f \sqrt{\frac{r}{s}} \left(e - 21.1\, m_0\, \delta\, r \log_e \frac{S}{r}\right)^2 10^{-5}$$

kw. per km. single conductor. (6)

Power loss (storm)

Power loss (storm) is higher and can generally be found with fair approximation by assuming $e_0 = 0.80$ of fair weather e_0 in (6).

Visual corona gradient—wires thoroughly wet (with fair approximation)

$$g_v = 6.4 \left(1 + \frac{0.815}{\sqrt{r}}\right) \text{ effective kv. per cm.}$$

Other Formulas. For spark-over formulas, corona in concentric cylinders, etc., see text.

NOTATION

$$\delta = \frac{3.92\,b}{273 + t}$$

b = barometric pressure in cm.
t = temperature in degrees cent.
f = frequency—cycles per second.
m_0 = irregularity factor.
= 1 for polished wires.
= 0.98 – 0.93 for roughened or weathered wires.
= 0.087 – 0.83 for cables.

$$m_v = \left\{ \begin{array}{l} \text{0.72 for local corona all along conductor} \\ \text{0.82 for decided corona all along conductor} \\ \end{array} \right\} \begin{array}{r} \text{For seven} \\ \text{strand} \\ \text{cables} \end{array}$$

= 1 to 0.93 for wires.
r = radius of wire in cm.
s = spacing in cm.

III. INFLUENCE OF TEMPERATURE AND BAROMETRIC PRESSURE ON VISUAL GRADIENT AND DISRUPTIVE GRADIENT

In the former paper* it was shown that the visual critical gradient for parallel wires may be expressed in maximum kv. per cm.

$$g_v = g_0 \left(1 + \frac{k}{\sqrt{r}}\right) = 29.8 \left(1 + \frac{0.301}{\sqrt{r}}\right)$$

at the standard temperature of 25 deg. cent. and barometric pressure of 76 cm. Also for changes in temperature and barometric pressure *over the natural range a fair approximation is*

$$g_v = 29.8\,\delta \left(1 + \frac{0.301}{\sqrt{r}}\right)$$

Where δ is the air density correction factor and is unity at the standard temperature and pressure.

$$\delta = \frac{3.92\,b}{273 + t}$$

b = barometric pressure.
t = temperature.

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* *Law of Corona and Dielectric Strength of Air*—I.

On the theory that definite energy is necessary to start disruption or glow,[*] g_0 should vary directly with the air density factor δ. g_v, however, should not vary directly with δ, as the thickness of the energy storage film should also be a function of δ. Thus, we would suspect that the equation for g_v should be written

$$g_v = g_0\,\delta\left(1 + \frac{k}{\phi\,(\delta)\,\sqrt{r}}\right)$$

Whether δ is varied by change of temperature or air pressure the effect should be the same as long as the temperature is not so high that the air is changed chemically. This will be discussed more fully later under the head of "Rupturing Energy."

TABLE I

FOR POLISHED COPPER TUBE INSIDE OF BRASS CYLINDER

Test 195 $r = 0.953$ $R = 5.55$ cm

Observed values				Calculated from equation			
Kv. effective	t C°	b cm.	δ	g_v (max)	g_v' (max)	k	$k\sqrt{\delta}$
48.5	18	75.4	1.016	40.7	41.4	0.286	0.285
46.5	37	"	0.954	39.1	39.1	0.312	0.305
45.2	50	"	0.915	38.0	37.7	0.327	0.312
43.4	66	"	0.873	36.5	36.2	0.337	0.314
41.0	85	"	0.826	34.5	34.5	0.339	0.308
39.6	100	"	0.793	33.3	33.3	0.344	0.306
37.6	119	"	0.754	31.6	31.9	0.342	0.297

Temperature Tests. A series of experiments on visual corona was carried on over a temperature range of −20 deg. cent. to 140 deg. cent. (All tests in this paper were made at 60 cycles unless otherwise specified.) The apparatus is shown in Fig. 1. It consists of a polished wire in the center of a brass cylinder. The cylinder was placed horizontally in a large asbestos lined "hot-box." Heating was effected by grids at the bottom of the box. The cylinder was shielded in such a way, and sufficient time was allowed to elapse after each change to get uniform temperature in the tube. Temperature was observed by a number of thermometers distributed in the "hot box."

After heating became uniform voltage was applied and gradually increased until glow appeared. The central con-

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[*] Part I. Pages 1535–1542.

PLATE LIX
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[PEEK]

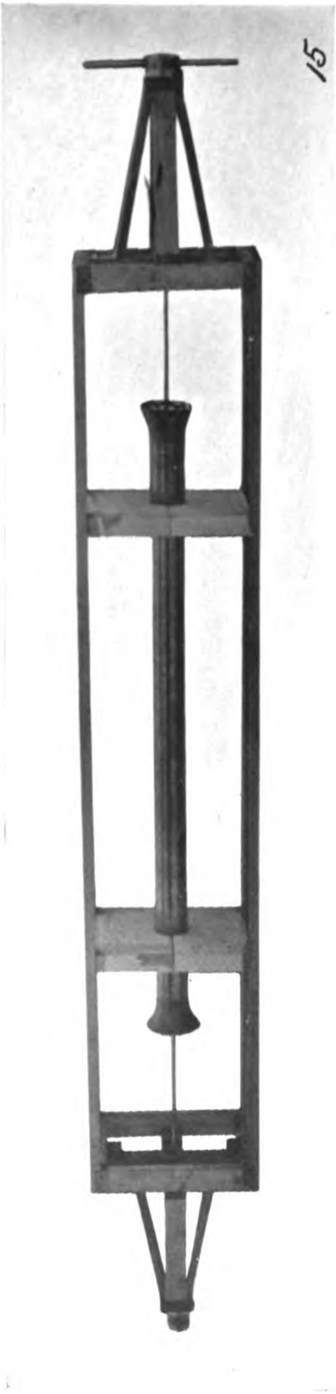

FIG. 1

ductor was observed through a window placed in such a position in the front part of the box that the whole length of the conductor could be seen. It was found that it made no appreciable difference in the starting voltage whether or not the box and tubes were " aired out " after each test. Concentric cylinders were used in this test rather than parallel wires, as the apparatus is more compact and requires a much smaller " hot box."

Three sizes of brass cylinders were used, having inside radii of 8.89, 5.55, and 3.65 cm., respectively. The central conductor ranged in size from 0.059 to 0.953 cm. radius. I and II are typical data tables.

TABLE II

FOR POLISHED COPPER TUBE INSIDE OF BRASS CYLINDER

Test 194 $r = 0.476$ cm. $R = 5.55$ cm.

Kv. effective	t	b	δ	g_v (max)	g_v' (max)	k	$k\sqrt{\delta}$
41.0	—13	75.5	1.139	49.6	50.0	0.279	0.298
40.0	0	"	1.084	48.3	48.0	0.304	0.316
37.0	20	74.9	1.001	44.8	44.9	0.306	0.306
35.7	41	75.5	0.942	43.2	42.7	0.331	0.312
33.2	70	"	0.863	40.1	39.7	0.342	0.318
31.5	87	"	0.823	38.1	38.1	0.342	0.310
29.5	121	"	0.753	35.7	35.4	0.361	0.313
28.7	130	"	0.734	34.7	34.7	0.358	0.308

$$g_v = \frac{e_v}{r \log_\epsilon \frac{R}{r}} \qquad g_v' = 31\,\delta\left(1 + \frac{0.308}{\sqrt{r\,\delta}}\right)$$

$$\delta = \frac{3.92\,b}{(273 + t.)}$$

Columns 1, 2, and 3 are the observed values. For concentric cylinders the gradient at the surface of the inner cylinder is

$$g = \frac{e}{r \log_\epsilon \frac{R}{r}}$$

Where e is volts between cylinders.

R is the inside radius of the outer cylinder.

r is the radius of the inside cylinder.

Column 4 is the surface gradient for the voltage e_v calculated directly from observed values. Hence, columns 1, 2, 3, 4 and 5 are observed values. As can be seen from the tables, and as already noted, g_v for a given r is independent of R or S, but varies with δ.

By Σ Δ reductions of all of the data the following equation connecting g_v with r and δ was obtained

$$g_v = g_0\,\delta\left(1 + \frac{r}{\phi\,(\delta)\;r}\right)$$

For concentric cylinder

$$g_v = 31\,\delta\left(1 + \frac{0.308}{\sqrt{\delta r}}\right) \text{ maximum kv. per cm.}$$

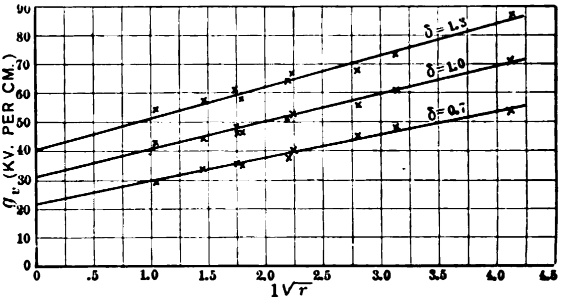

FIG. 2.—EFFECT OF TEMPERATURE UPON VISUAL CORONA; $\dfrac{1}{\sqrt{r}} - g_v$ CURVES.

These curves show straight-line relation between g_v and $\dfrac{1}{\sqrt{r}}$ for constant δ. therefore at given δ, $g_v = g_0\left(1 + \dfrac{K}{\sqrt{r}}\right)$

For parallel wires,

$$g_v = 29.8\,\delta\left(1 + \frac{0.301}{\sqrt{\delta r}}\right) \text{ maximum kv. per cm.}$$

Referring to the tables, column 6 gives values of g_v calculated from the above equation. Column 5 gives observed values. It is seen that the difference is generally less than 1 per cent throughout the whole range. Column 7 gives values of k calculated from observed values of g_v and for $g_0 = 31$. In Figs. 2, 3 and 4 the drawn lines are the actual calculated values, while the crosses are observed values.

g_0 has a slightly higher value for wires in a concentric cylinder than for parallel wires. This does not mean that the strength of air differs in the two cases. For a wire in a concentric cylinder the field is balanced all around and uniform, and should give more nearly the true value. For parallel wires there is never complete balance, even where S/r is large. This gives g_0 an apparent value which is slightly lower.

Barometric Pressure. It is now interesting to see if the same law holds if the temperature is kept constant and δ is varied by changing the barometric pressure. Taking the curves by Whitehead* in Fig. 5 the drawn lines are directly as plotted in

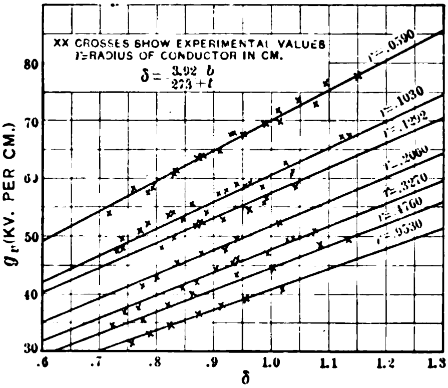

FIG. 3—EFFECT OF TEMPERATURE UPON VISUAL CORONA; $\delta\ g_v$ CURVES.

Curves are drawn from calculated values, from $g_v = 31\delta\left(1 + \frac{0.308}{\delta r}\right)$

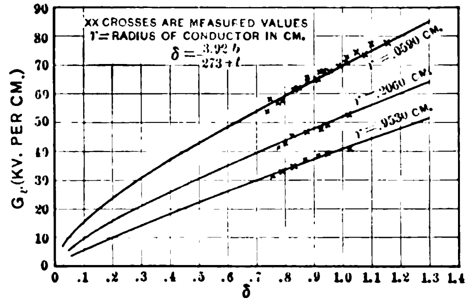

FIG. 4.—EFFECT OF TEMPERATURE UPON VISUAL CORONA; $\delta\ g_v$ CURVES.

Curves drawn from equation $g_v = 31\delta\left(1 + \frac{0.308}{\sqrt{\delta r}}\right)$

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* *Electric Strength of Air II* (Figs. 6 and 7), J. B. Whitehead, PROCEEDINGS A. I. E. E., June, 1911.

" Electric Strength of Air, II." The circles are points calculated from the equation

$$g_v = 31\,\delta\left(1 + \frac{0.308}{\sqrt{\delta r}}\right)$$

The check is quite remarkable, and the law seems to apply equally well for temperature or pressure.

IV. Influence of Frequency on Visual Gradient

The effect of frequency on g_v for the practical range of 25 *to* 60 *cycles, if any, is very small and can be neglected.* A few measurements are shown in Fig. 6. For the test range it is difficult to tell whether the slight variations are due to changes in wave shape too small to be detected by the oscillograph, or to frequency. The points show a tendency to decrease with increasing frequency. There is a possibility of frequency entering thus as a function in

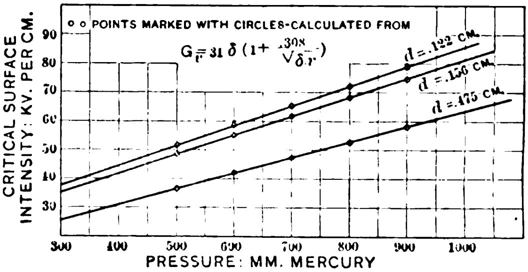

Fig. 5.—Data for Lines taken from Whitehead's " Electric Strength of Air, II," Proceedings A. I. E. E., June, 1911, p. 1099—Fig. 6.

$$g_v = g_0\,\delta\left(1 + \frac{k}{\phi\,(f)\,\sqrt{\delta r}}\right)$$

Investigation of this over a very wide range of frequency will be of great theoretical interest. Direct-current points by Watson are also given on curves (Fig. 6). It is interesting to note that these points do not indicate increased g_v at lower frequencies.

While g_v over the commerical transmission range is not appreciably affected by frequency, it must be remembered that the *power loss over this range with sufficient accuracy for practical calculation* increases directly with the frequency as shown in Part I. It will also be of theoretical interest to investigate this over a very wide range of frequency. The difficulties in making such a comparison even over a short range are many due to changes in wave shape, power factor, etc.

V. Relation Between Spark-Over and Corona for Parallel Wires and Concentric Cylinders

If impressed voltage is gradually increased on two parallel wires placed a considerable distance apart, in air so that the ratio S/r is above a ***certain minimum*** value the first evidence of stress in the air is visual corona. If voltage is still further increased the wires become brighter and the corona has the appearance of extending further out from the surface. Finally, when the voltage has been sufficiently increased, at some chance place, a spark will bridge between the conductors. When the spacing is small, so that S/r has a certain ***minimum value***, spark and corona may occur simultaneously, or the spark may bridge across before corona appears. This value of S/r is a critical ratio. If the spacing is still further reduced so that S/r is below the critical ratio the first evidence of stress is complete spark-over and corona never appears.

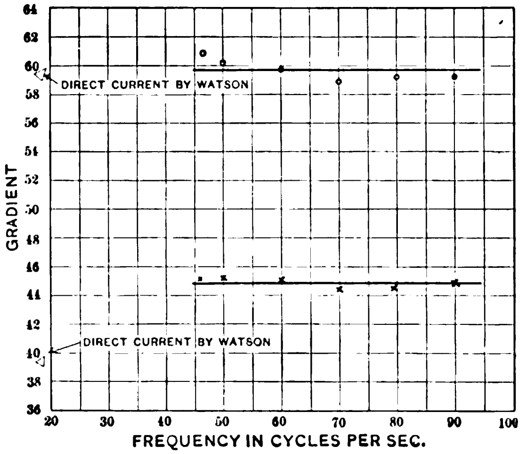

Fig. 6.—Variation of Gradient with Frequency.
These curves are plotted to an exaggerated scale to magnify any variations.

A considerable number of tests were made to study spark-over and corona on parallel wires. The conductors in these tests were supported on wooden wheels in a wooden frame work as in former tests for visual corona, except that the wires were not allowed to come in contact with the wood at point of support, but rested on aluminum shields spun on a curve over the end wheels. See Fig. 7. This method of support was found necessary, as otherwise spark-over always took place at the ends. The apparatus worked very well except for very large or very small conductors, when it was found almost impossible to support the wires without spark-over at the shields.

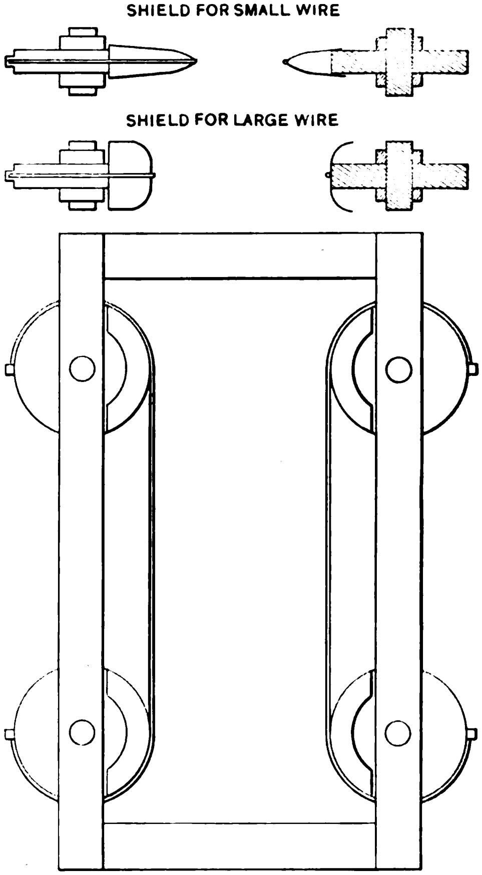

Fig. 7

The conductors ranged in size from 0.15 cm. to 1.00 cm. in diameter, and the spacing for spark-over from 1.2 to 30 cm. The temperature was kept nearly constant. The conductors were were polished after each test.

The method of test was to start at the smaller spacing with a given value of *r* and measure the spark-over voltage. The spacing was increased by steps and spark voltage measured. When the spacing was above the critical ratio of S/r, where corona formed before spark-over, the corona voltage was noted first. The voltage was then increased until spark-over occurred. The spark-over point is not as constant or consistent* as the corona point and is susceptible to change with the slightest dirt spot on the conductor surface, and any unsteady condition in the circuit, etc. At the beginning of the tests it was found necessary, in order to get consistent results, to put water tube resistances in series with the conductoss to eliminate resonance. These resistances were high, but not sufficiently so to cause an appreciable drop in voltage before arc-over.

TABLE III

CORONA AND SPARK-OVER FOR PARALLEL WIRES

Test No. 166 No. 0 wire
Values read Connected to 25 deg. cent. — 76*b*

Spacing	Effective kv. to neutral		Maximum values			
Cm. S	Corona e_v	Spark e_s	Corona e_v	Spark e_s	Corona g_v	Spark g_s
2.54	None	15.8	—	21.9	—	41.4
3.81	"	22.5	—	31.2	—	42.5
5.08	"	27.3	—	37.9	—	43.2
6.35	"	31.05	—	43.2	—	43.8
7.62	"	35.0	—	48.5	—	44.9
8.89	"	37.35	—	51.8	—	45.0
10.16	40.4	40.9	56	56.7	44	44.6
12.70	41.8	42.1	58	58.1	44	44.1
13.97	43.7	46	63.7	60.5	44.2	46.7
15.24	45.9	48.1	63.6	67	45.1	48.9
15.78	46.6	54.1	64.8	75	43.8	50.8
20.32	48.9	59.6	67.7	82.8	44	53.7
22.86	50.1	66.2	69.7	91.7	43.7	56.8
25.40	51.1	71.5	70.7	99.2	43.1	60.4
27.94	52.1	79	72.4	109.7	42.9	65.1
30.48	53.1	84.5	74	117	42.9	67.9
33.02	54.1	89.6	74.8	124	42.4	70.2
35.56	55.1	95.5	76.5	132.5	42.6	73.9
38.10	56.1	102.3	77.8	141.9	42.7	77.8
40.64	57.1	106.5	79.4	149	42.9	80.5
60.96	63.3	—	87	—	42.9	—

Temperature 17 deg. cent. Bar. 75.3 cm.
Wire No. 0. Diameter 0.825 cm.

Table III is a typical data table. Each point is the average of a number of readings.

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* Above the critical ratio of S/r, or where corona forms first.

In columns 4 and 5 are voltages reduced to maximum value to neutral and corrected to standard δ. Column 6 is the surface gradient for corona while column 7 is surface gradient for spark up to

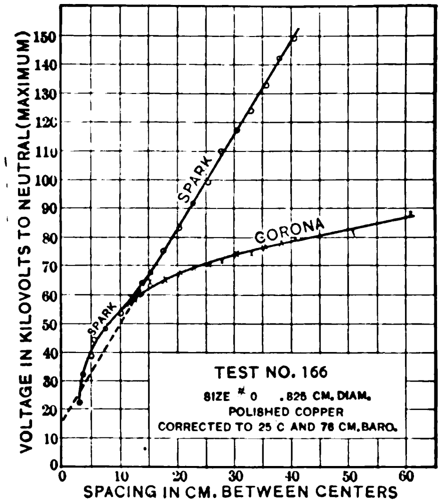

FIG. 8A.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

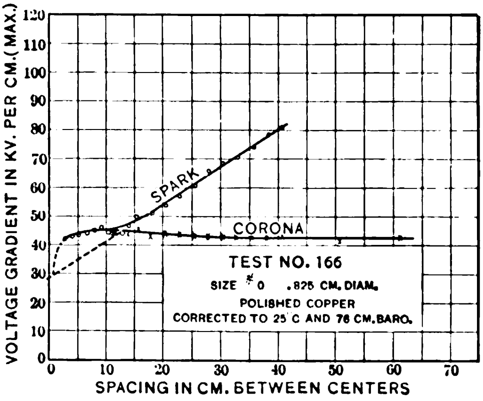

FIG. 8B.—SPARK AND VISUAL CORONA VOLTAGE GRADIENTS FOR PARALLEL WIRES.

the spacing where corona starts first; above this critical spacing it is the *apparent surface gradient* as the conductor above this point must be larger on account of corona. As the field around the conductors at the small spacings is very much distorted it is necessary to use the following rather complicated formulas to calculate the surface gradient.

$$g = \frac{e}{\frac{D\,r}{p}\log_e \frac{p+D}{p-D}}$$

where

$$D = \frac{S - 2\,r}{2}$$

S = distance between conductor centers.
r = conductor radius.

$$p = D\sqrt{1 + \frac{2\,r}{D}}$$

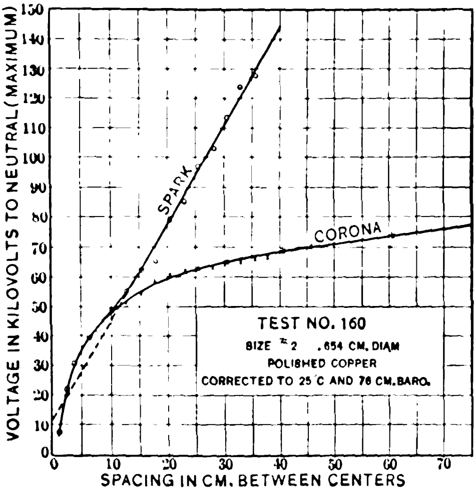

FIG. 9A.—SPARK AND VISUAL VORONA VOLTAGES FOR PARALLEL WIRES.

Fig. 8A is a typical curve. Voltage is plotted with spacing for spark and corona. Up to spacing 12.4 cm. there is spark-over before corona. This curve seems to be continuous with the corona curve which starts at this point. The spark curve here branches and is very close to a straight line within the voltage range. Looking at Fig. 8B the surface gradient curves are plotted. The corona gradient is a straight line parallel to the X axis with a slight lump at the critical ratio of S/r. The apparent spark gradient is also a straight line, within the test range. It intersects the corona line at the critical ratio point, or at what may be termed the triangular point, and extended cuts the g axis at $g = 30$. Fig. 9 to 12 give similar curves for different sizes of wire. For a given spacing the spark-over voltage increases as the size of the conductor decreases.

It is important to note that for all sizes of wire the spark gradient curve extended as a straight line cuts the gradient axis

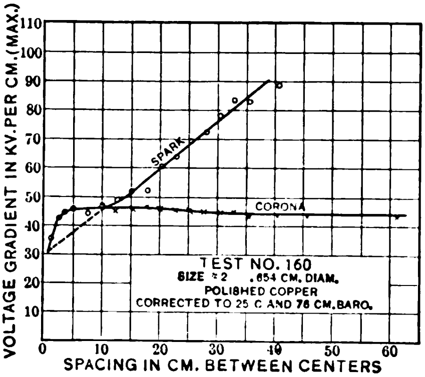

FIG. 9B.—SPARK AND VISUAL CORONA VOLTAGE GRADIENTS FOR PARALLEL WIRES.

at $g = 30$. That is, at zero spacing where compared with the distance apart the conductors are plane surfaces, the gradient has the same numerical value as the ***disruptive gradient*** g_0. This seems to be a further check on g_0. Spark curves extended as straight lines through the critical ratio point and intersecting the gradient axis at $g = 30$ are shown in Fig. 13. The triangular point or critical ratio of S/r is tabulated in Table IV.

TABLE IV

CRITICAL RATIOS S/r—EXPERIMENTAL VALUES

Size—B. & S.	Radius cond. cm.	S cm.	S/r
0	0.461	13.5	29.3
0	0.412	11.7	28.4
2	0.327	10.2	31.2
4	0.260	7.9	30.4
5	0.230	7.3	31.7
6	0.205	6.2	30.2
8	0.162	4.8	29.6
10	0.129	4.0	31.0
12	0.103	3	29.1
			Average 30.1

Intersection point of g_v and g_s.

Its average value is $S/r = 30$. If we assume that the spark gradient curve is a straight line the conditions are, that it must cut the corona gradient line at $S/r = 30$ and extended must cut the g axis at $g_0 = 30$. The equation for g_v is

$$g_v = 30\left(1 + \frac{0.301}{\sqrt{r}}\right) \tag{5a}$$

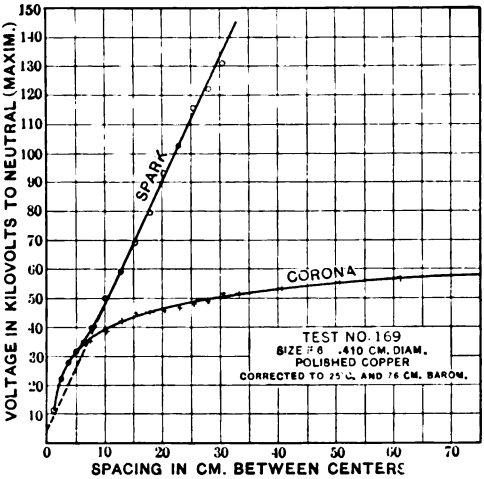

FIG. 10A.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

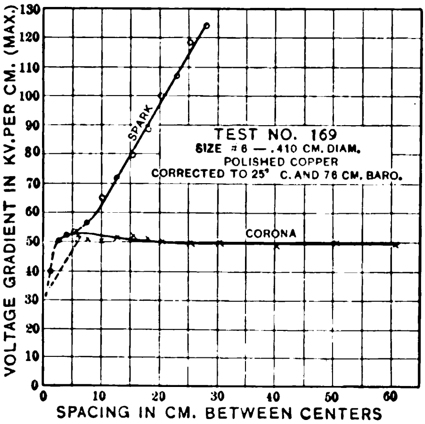

FIG. 10B.—SPARK AND VISUAL CORONA VOLTAGE GRADIENTS FOR PARALLEL WIRES.

therefore

$$g_s = g_0\left(1 + \frac{0.301}{\sqrt{r}}\,\frac{S}{r}\,\frac{1}{30}\right)$$

$$= 30\left(1 \times \frac{0.01}{\sqrt{r}}\,\frac{S}{r}\right) \text{ kv. per cm. max.}$$

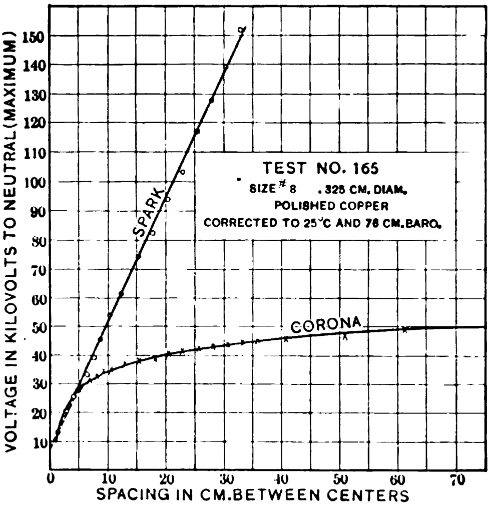

Fig. 11a.—Spark and Visual Corona Voltages for Parallel Wires.

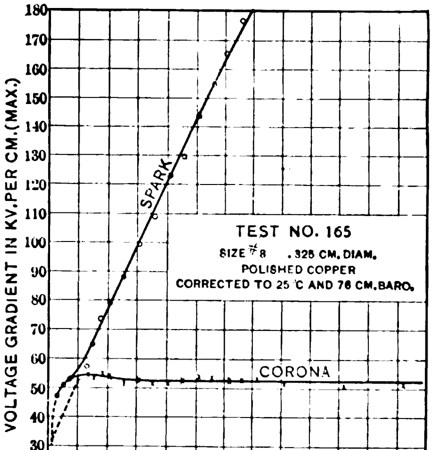

Fig 11b.—Spark and Visual Corona Voltage Gradients for Parallel Wires.

At $S/r = 30$, g_s reduces to g_v and formula (5*a*) should be used

$$e_s = g_s\, r \log S/r \text{ kv. to neutral max.}$$

or more accurately

$$e_s = g_s \frac{r \log S/r}{1 + \dfrac{2r}{S - 2r}}$$

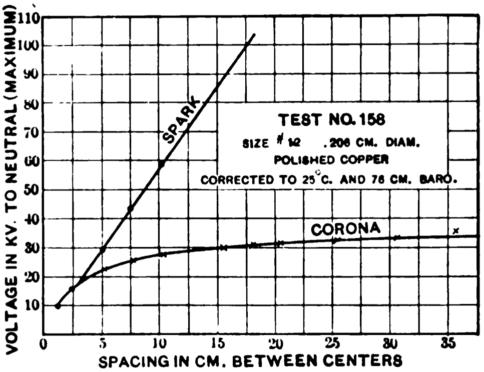

FIG. 12A.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

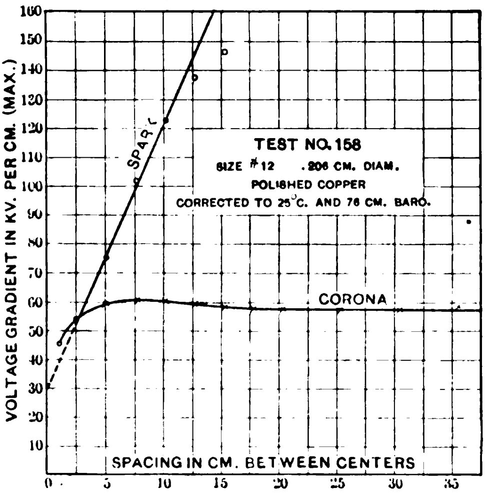

FIG. 12B.—SPARK AND VISUAL CORONA VOLTAGE GRADIENTS FOR PARALLEL WIRES.

In Fig. 13 each drawn curve is for g_s values calculated for varying spacing at constant radius. The points are measured values. The corona boundary line is the g_v curve; it intersects the g_s curves at $S/r = 30$. Corona does not form below this line, but spark jumps across immediately.

In Fig. 14 each curve is drawn for a constant spacing and varying radius. The broken line is the critical ratio line; it also corresponds to the g_v curve. For spacing below this line spark takes place immediately before corona forms, and the g_s values fall pretty well on the g_v line as shown by triangles. They generally fall a little low.

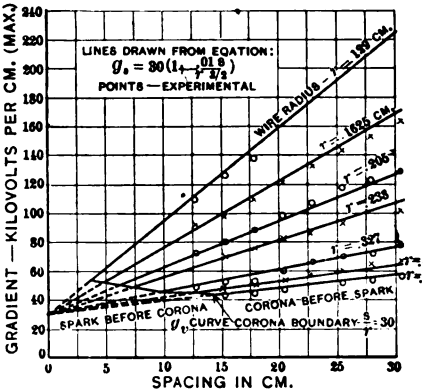

FIG. 13.—SPARK-OVER GRADIENTS FOR PARALLEL WIRES.

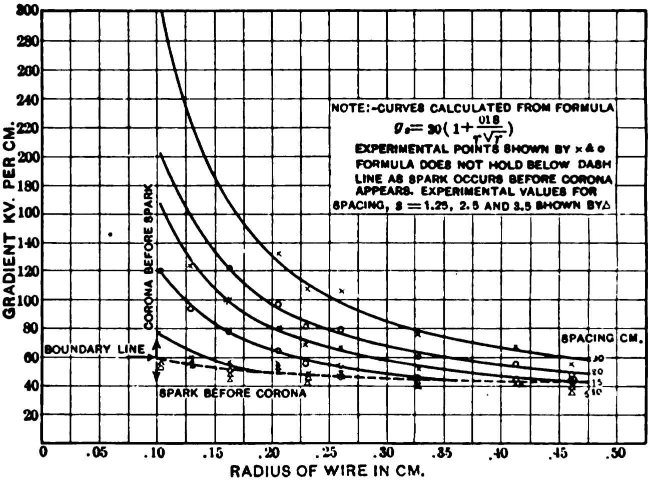

FIG. 14.—RELATION BETWEEN SPARK-OVER GRADIENT AND RADIUS OF WIRE FOR SPARK BETWEEN PARALLEL WIRES.

Fig. 15 is voltage plotted in the same way. Below the corona boundary where spark occurs before corona—the e_s curve does not hold. The broken lines are calculated from g_v and e_v.

The points are observed values. Thus corona gradient and spark-over gradient and hence spark voltage and corona voltage below $S/r = 30$ are the same.

In Fig. 16 the drawn lines are calculated from

$$e_s' = 3.4\,S + \frac{S+5}{2.5\sqrt{r}} \text{ maximum kv. to neutral}$$

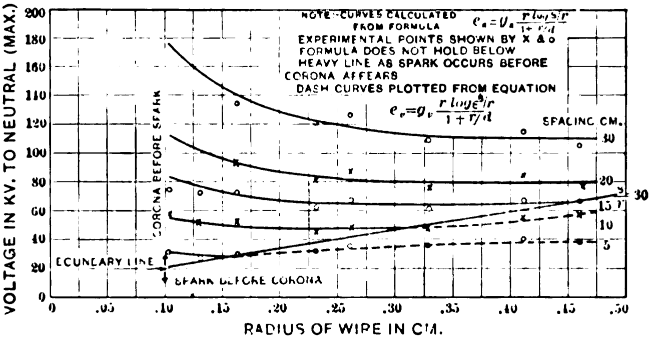

FIG. 15.—RELATION BETWEEN VOLTAGE AND RADIUS OF WIRE FOR SPARK BETWEEN PARALLEL WIRES.

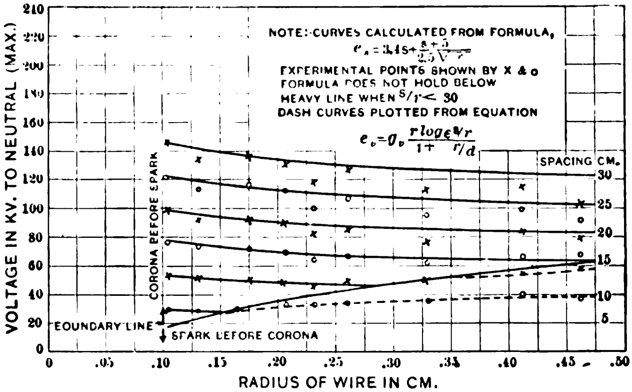

FIG. 16.—RELATION BETWEEN VOLTAGE AND RADIUS OF WIRE FOR SPARK BETWEEN PARALLEL WIRES.

This formula is based on the assumption that all sizes of wire for a given spacing would spark over at the same voltage if there were no "corona resistance."

For no "corona resistance," spark would take place where $S/x = 30$, where x is the diameter of conductor and corona, and g_0 at $x = 30$ kv. per cm.

That is $3.4\,S -$.

However, as small wires require higher voltage than larger ones there is a " drop " due to corona resistance which is a function of r. From experiments

$$e_d = \frac{S + 5}{2.5\sqrt{r}}$$

Hence total spark-over voltage is

$$e_s' = 3.4\,S + \frac{S + 5}{2.5\sqrt{r}}$$

The measured points do not follow this formula as well as the one based on a straight line gradient. The method of derivation, however, is interesting.

The reason that spark takes place before corona can form at small spacing or below $S/r = K$ can be seen as follows:

Considering first a wire in the center of a cylinder

$$g_v = \frac{e_v}{r \log_\epsilon R/r}$$

$$e = g_t\, r \log_\epsilon R/r$$

Assuming g and R constant, increasing r increases e up to a certain maximum point where e begins to decrease. Thus at the maximum value of e the effect of reducing the flux density by increasing r is overcome by decreasing the distance between cylinders or reducing the ratio R/r. Below the ratio $R/r = K_1$ for maximum e corona would appear, then as e is increased corona would increase r to x or the ratio to $R/x = K_1$. As this ratio requires a lower voltage for corona, spark must pass between the cylinders. Under the above assumptions, for maximum e $R/r = \epsilon$. Thus corona would appear before spark up to $R/r = \epsilon$. Where R/r is less than ϵ spark over must occur before corona. The ratio $R/r = \epsilon$ is generally taken as the ratio for maximum dielectric strength of concentric cylinders. This does not seem correct as in the above assumption g_v was taken as constant. We know, however, that g_v is a function of r, and for air is:

$$g_v = g_0\left(1 + \frac{0.301}{\sqrt{r}}\right)$$

$$e = g_0\left(1 + \frac{0.301}{\sqrt{r}}\right) r \log_\epsilon R/r$$

Differentiating for maximum

$$\frac{d\,e}{d\,r} = g_0 \left[\left(1 + \frac{0.301}{2\sqrt{r}}\right) \log_\epsilon R/r - 1 - \frac{0.301}{\sqrt{r}}\right]$$

or

e is maximum when

$$\left[\left(1 + \frac{0.301}{2\sqrt{r}}\right) \log R/r - 1 - \frac{0.301}{\sqrt{r}}\right] = 0$$

This gives a ratio of R/r greater than ϵ. The experimental ratio in Fig. 17 is 3 and checks with above.

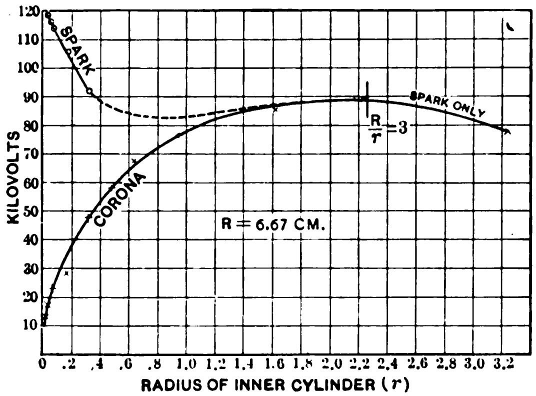

FIG. 17.—RELATION OF CORONA AND SPARK-OVER FOR CONCENTRIC CYLINDERS.

If a very small value of *r* is taken so that corona forms and the voltage is increased spark-over finally occurs. It might be supposed that as the voltage were increased the center wire would become larger and larger in effect due to conducting corona and finally, when *R*/corona radius = critical ratio, spark-over would occur. This is not the case. It takes a much higher voltage for the small wire + corona than for metallic cylinders for maximum ratio. Hence corona seems to be either in effect a series resistance, or grades or distributes the flux density. See Fig. 17. This has an important bearing on the study of the power loss equation.

Taking now the exact equation for parallel wires

$$g_v = \frac{e_v}{\frac{D\,r}{p}\,\log_e \frac{p+D}{p-D}}$$

$$e_v = g_0\left(1 + \frac{0.301}{\sqrt{r}}\right)\frac{D\,r}{p}\,\log_e \frac{p+D}{p-D}$$

Varying r for constant $S = 10$ it is found that e_v is maximum when $S/r = 6.67$. See Fig. 18. Experiments show this ratio to be 30. The difference is evidentally due to the distorted condition of the field at the small spacings.

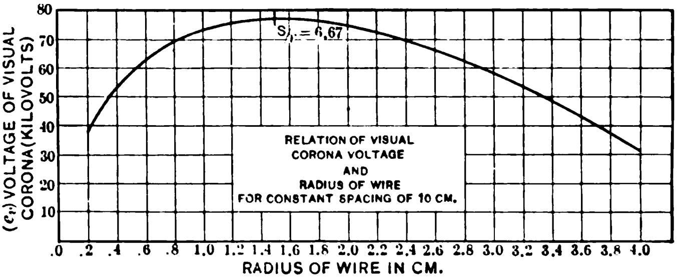

Fig. 18

The visual corona voltages, or the spark-over voltages *below* the critical ratio of S/r or R/r, should be of practical value for voltage measurement on account of the accuracy at which they may be determined or calculated for different temperatures, barometric pressures, etc.

VI. Influence on Corona and Spark-Over of Water and Oil on the Conductor Surface

These tests were made in a manner exactly similar to the dry spark-over and corona tests. In the oil tests, the surface of the wire was coated with a thin even film by means of an oiled rag. For the wet tests water was sprayed on the conductor surface after each reading by means of an atomizer. Figs. 19-23 are dry, wet and oil curves for three different sizes of wire.

For spark-over both water and oil have approximately the same

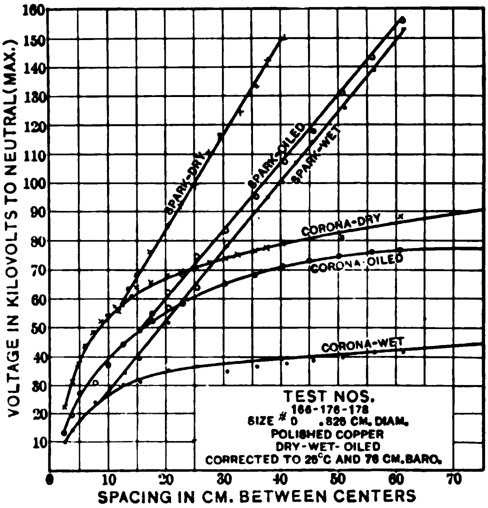

FIG 19.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

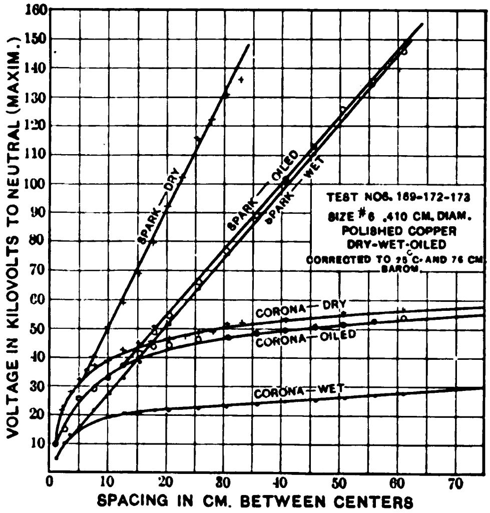

FIG 20.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

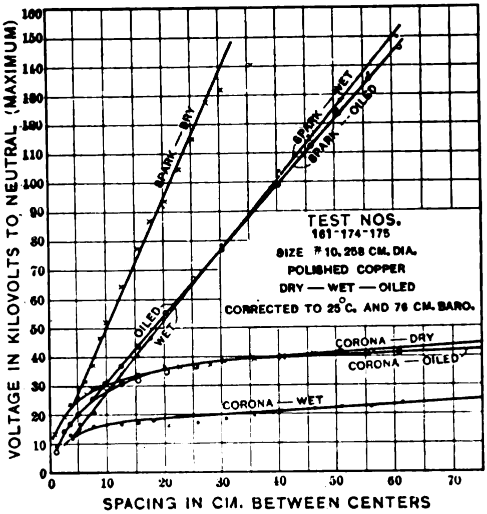

FIG. 21.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

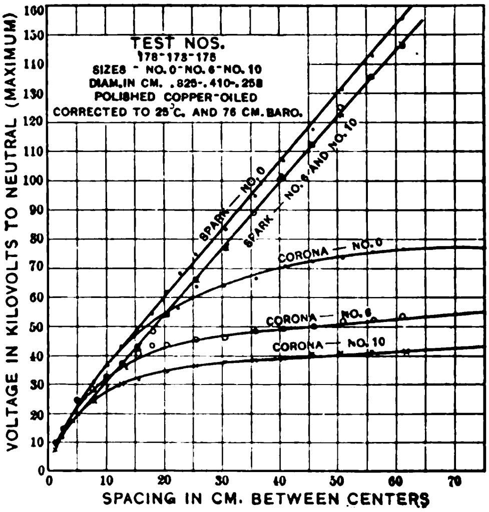

FIG. 22.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

effect, that is, give very nearly the same spark over voltage for all sizes of conductor. This curve very closely follows the needle gap curve.

For corona water very greatly lowers g_v. Oil lowers g_v but to a much less extent than water. Where the conductor is very small the per cent increase in diameter due to oil more than compensates for the lowering effect. The visual corona gradient (max.) for oil and water coated conductors may be found.

Water surface by fine spray or fog.

$$g_v = 9\left(1 + \frac{0.815}{\sqrt{r}}\right)$$

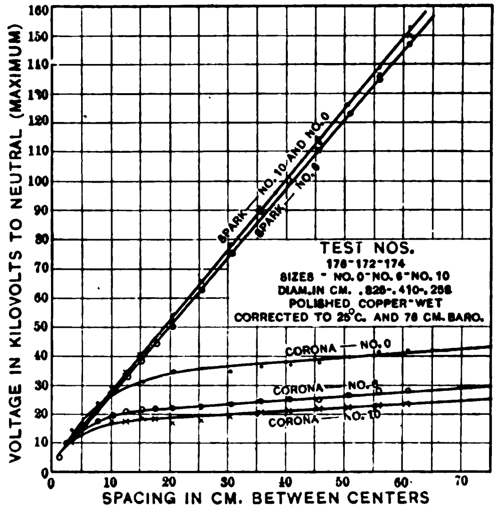

FIG. 23.—SPARK AND VISUAL CORONA VOLTAGES FOR PARALLEL WIRES.

Oil film surfaces.

$$g_v = 19\left(1 + \frac{0.65}{\sqrt{r}}\right) \quad \text{See Fig. 24.}$$

VII. SOME ADDITIONAL REMARKS ON DISRUPTIVE GRADIENT—g_0

Fig. 25 shows three entirely different methods which all seem to indicate a constant disruptive gradient of $g_0 = 30$ for air, as follows

a. *By Visual Corona.*

$$g_v = 30\left(1 + \frac{0.301}{\sqrt{r}}\right)$$

b. *By Power Measurement.* This curve is plotted between the square root of measured power and the surface gradient g. The curve intersects the axis at $g = 30$ or

$$p = m\,(g - g_0)^2 = m\,(g - 30)^2$$

c. *By Spark-Over Between Parallel Wires.* This curve is plotted between gradient and spacing. The curve, extended to zero spacing,—where r may be considered a plane compared with S—intersects the g axis at $g_0 = 30$.

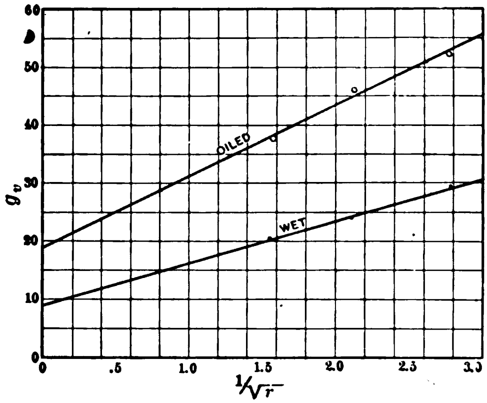

FIG. 24.—RELATION OF g_v TO $1/\sqrt{r}$

VIII. RUPTURING ENERGY OF AIR

It is now of theoretical interest to investigate the energy in a zone surrounding the surface of the conductor just at the instant before visual corona, when the outer boundary of the zone is equigradient circle g_0, and the inner boundary, the conductor surface at gradient g_v.

The tests for visual corona show that the surface gradient, g_v, for the first appearance of visual corona is not constant for all sizes of conductors, but is a function of the radius, r, of the conductors. g_v increases as r decreases. From the equations, when δ = unity

$$g_v = \frac{e_v}{r \log_e s/r}$$

$$g_0 = \frac{e_v}{(r + x) \log_e s/r}$$

It seems that air has a constant breakdown gradient g_0 for given density δ, but that energy is necessary to start rupture.

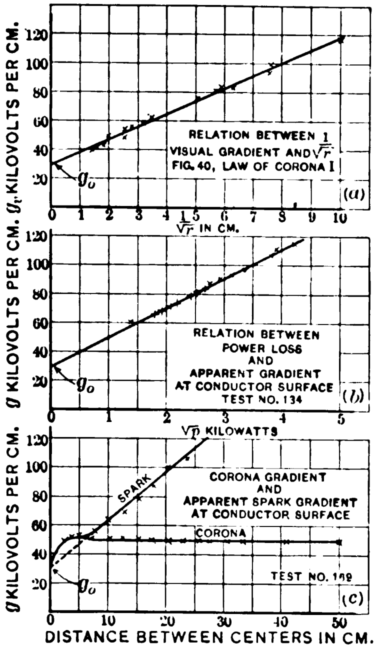

FIG. 25.—DIFFERENT METHODS OF OBTAINING g_0.

This means that rupture cannot occur at the surface of the conductor when the surface stress becomes g_0, but only after the gradient reaches a higher value, g_v, at the conductor surface and, hence, g_0, at a finite distance x from the conductor surface when rupture occurs. The energy stored in the zone between g_v and g_0 may hence be called the "rupturing energy."* See Fig. 26.

---

* This must not be confused with the power lost by corona. It is the energy stored between g_v and g_0 to start rupture, or up to the point where loss begins.

The rupturing energy for a conductor of radius r, and one cm. long and $\delta = 1$ may be calculated thus:

$$g_v = \frac{e_v}{r \log_\epsilon s/r}$$

From experiments

$$g_0 = \frac{e_v}{(r + \phi\, r) \log_\epsilon s/r} = \frac{e_v}{(r + 0.301 \sqrt{r}) \log_\epsilon s/r} = 29{,}800$$

Therefore $0.301 \sqrt{r}$ is the thickness of the energy film x, and $(r + 0.301 \sqrt{r})$ is the outer radius of the energy cylinder.

Also

$$e_v = (r + 0.301 \sqrt{r})\, g_0 \log_\epsilon s/r$$

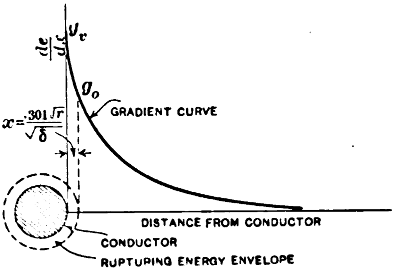

FIG. 26.—RUPTURING ENERGY IN AIR SURROUNDING ONE OF TWO PARALLEL CONDUCTORS.

From Fig. 26; rupturing energy is found

$$d\,\omega = \frac{K}{2} g^2\, d\,V$$

where $K = 0.08842\ 10^{-12}$ coulombs per volt per cm. thickness of dielectric (air) per square cm. cross-section,

but

$$d\,V = 2\,\pi\, y\, dy$$

therefore

$$d\,\omega = \pi\, K\, g^2\, y\, dy$$

Therefore

$$\omega = \pi\, K \int_{y = r}^{y = (r + 0.301 \sqrt{r})} g^2\, y\, dy$$

substituting

$$g = \frac{e_v}{y \log_\epsilon s/r}$$

$$\omega = \frac{\pi K e_v^2}{(\log_\epsilon s/r)^2} \int_{y=r}^{y=(r+0.301\sqrt{r})} \frac{dy}{y}$$

but

$$e_v = (r + 0.301\sqrt{r})\, g_0 \log_\epsilon s/r$$

Therefore

$$\omega = \pi K g_0^2 (r + 0.301\sqrt{r})^2 \log_\epsilon \frac{r + 0.301\sqrt{r}}{r}$$

$$\omega = 25\, (r + 0.301\sqrt{r})^2 \log_\epsilon \left(\frac{r + 0.301\sqrt{r}}{r}\right) 10^{-5} \text{ joules.}$$

ω is the energy in joules that must be stored around the surface of the wire per cm. length of conductor to start corona at $\delta = 1$. It is seen that the rupturing energy increases as r increases. The rupturing energy is independent of S—that is, g_v for a given wire must be independent of S, which is borne out by experiment and is an interesting point.

From the section under temperature and pressure it is seen that

$$g_v = g_0 \delta \left(1 + \frac{k}{\sqrt{r\delta}}\right)$$

This apparently means that the disruptive gradient g_0 varies directly with the air density δ. Also that the energy storage distance x increases, as δ and g_0 decreases.

$$x = \frac{0.301\sqrt{r}}{\sqrt{\delta}}$$

Then

$$g_0 \delta = \frac{e_v}{\left(r + \frac{0.301\sqrt{r}}{\sqrt{\delta}}\right) \log s/r}$$

Introducing δ into the energy equation

$$\omega = 25 \left(r + \frac{0.301 \sqrt{r}}{\sqrt{\delta}} \right)^2 \log \frac{r + \frac{0.301 \sqrt{r}}{\sqrt{\delta}}}{r} 10^{-5} \text{ joules per cm. conductor.}$$

In Fig. 27 the "rupturing energy" calculated from the above is plotted for different conductor radii and at $\delta = 1$ to show the energy increase with increasing r.

In Fig. 28 the "rupturing energy" for a given size conductor is plotted with δ. This curve shows that energy to start rupture increases almost directly with the air density.

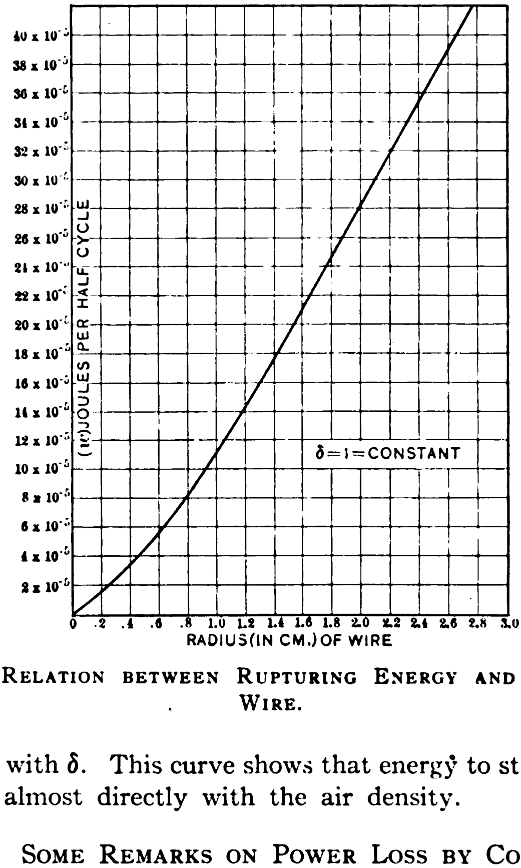

FIG. 27.—RELATION BETWEEN RUPTURING ENERGY AND RADIUS OF WIRE.

IX. SOME REMARKS ON POWER LOSS BY CORONA

The equation for power loss by corona on parallel wires

$$p = K'/\delta f \sqrt{r/S} \, (e - g_0 \, m \, r \, \delta \log S/r)^2 \times 10^{-5} \qquad (6)$$

at $\delta = 1$ and $m_0 = 1$

$$p = K' f \sqrt{r/S} \, (e - e_0)^2 \times 10^{-5} \qquad (6')$$

For a wire with a given radius r and ***uniform dielectric flux distribution*** it would be expected that the loss for a given apparent surface gradient, g, would be the same, independent of S, or

$$p = K'' \phi (r) f (g - g_0)^2$$

Equation (6′) may be written

$$p = K' f \sqrt{r/S} (\log S/r)^2 r^2 (g - g_0)^2 \times 10^{-6}$$

Thus for a ***uniform field*** the terms $\sqrt{r/S} (\log S/r)^2$ should cancel and the equations become

$$p = K' f r^2 (g - g_0)^2$$

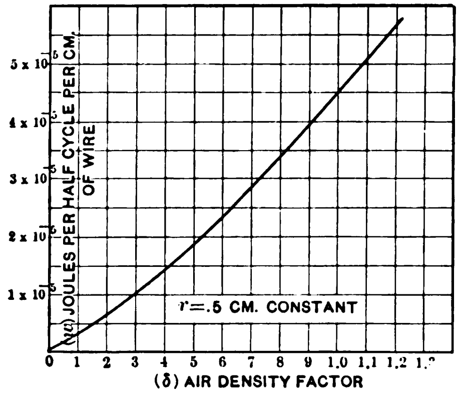

FIG. 28.—VARIATION OF RUPTURING ENERGY WITH AIR DENSITY

Fig. 29 shows measured curves plotted between g and $\sqrt{p}$ for a given wire at three different spacings. These curves all intersect the axis at g_0 max. = 30, at $\delta = 1$. S enters as a function, otherwise all of the points would be on the same line. Hence for parallel wires when corona starts it acts somewhat as a flexible conductor in which the radius of curvature can change. The slightly non-uniform field, even with large values of S/r, starts distortion, and the effect is accumulative. For a given value of g the loss should therefore be greater at small s than large S. Experiments show this to be the case.

The equation derived for the average spacing is

$$p = 500 f r^2 (g - g_0)^2 \times 10^{-6}$$

$$g = \text{effective gradient } g_0 = 21.2$$

This should be the form of the equation for loss in concentric cylinders. For parallel wires it gives values too high at the larger and too low at the smaller values of S/r. The error for parallel wires neglecting $\phi(S)$ is usually below 20 per cent.

This effect of spacing is brought up here as an interesting point in the complication of the mechanism of corona loss and one of the almost innumerable influences that must be considered in rationalization. Another point of considerable interest is the loss per cycle over a longer frequency range.

X. STROBOSCOPIC STUDY OF CORONA

A study of the power loss equation leads one to suspect that the mechanism of corona loss is more complicated than might at first be supposed. This is also indicated by many peculiar phenomena* of the spark discharge. For instance, while investigating a-c. spark-over and corona for parallel wires it was observed that when the end shields are not used, and the wires come directly in contact with the wooden wheel supports, corona often appears to bridge completely between the conductors without dynamic arc. In this case it seemed possible that the corona on, say, the positive wire, extended out further than the corona on the negative wire, then as each wire is alternately positive and negative, the positive discharges overlap and combine in the eye,

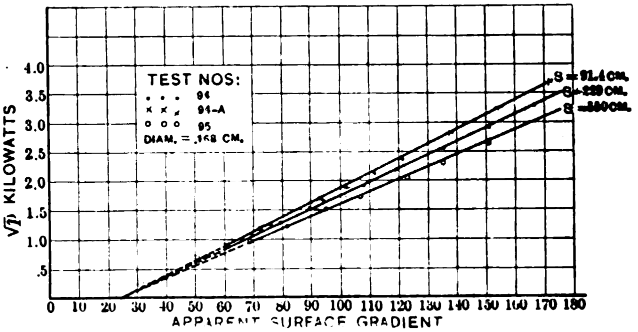

FIG. 29.—RELATION BETWEEN POWER LOSS AND APPARENT SURFACE GRADIENT.

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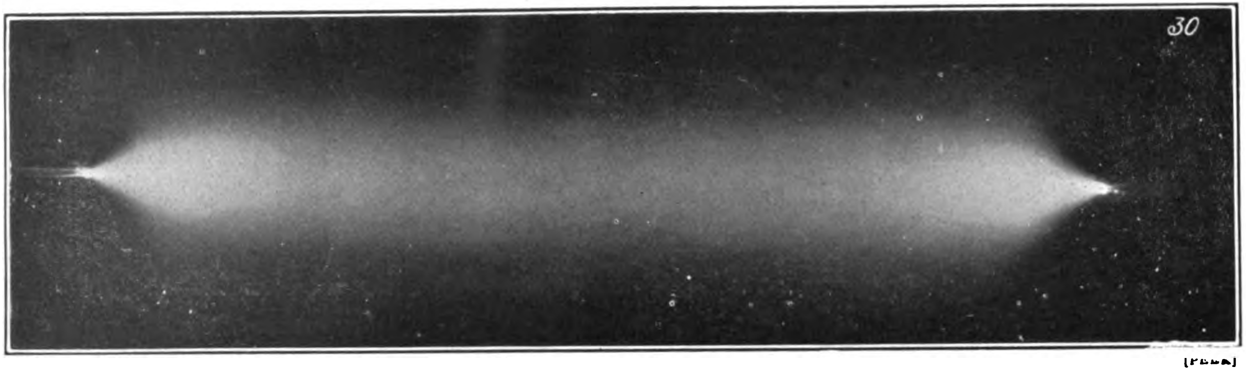
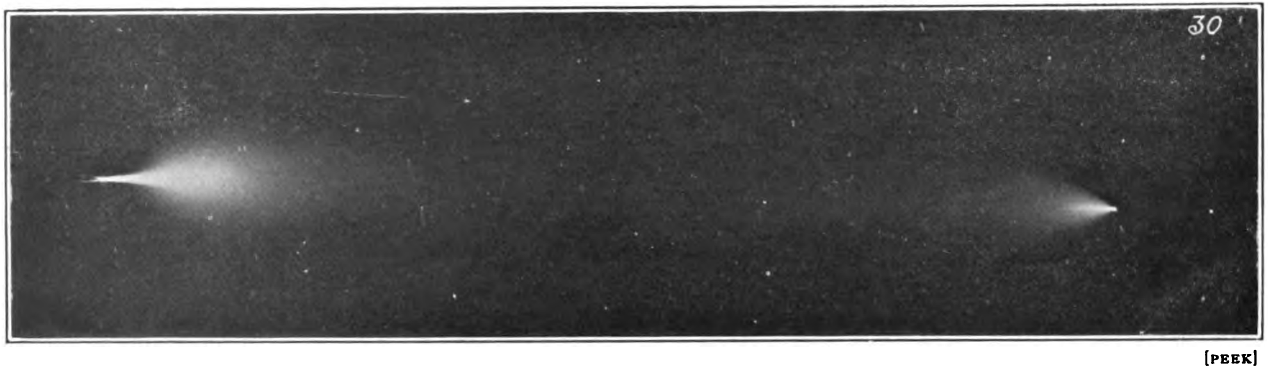
*An interesting one observed by Mr. C. W. Stone is that in the automobile spark plug; it makes considerable difference in firing which polarity is connected to the pointed electrode. Best results are obtained when the negative is connected to the point, indicating a hot negative.

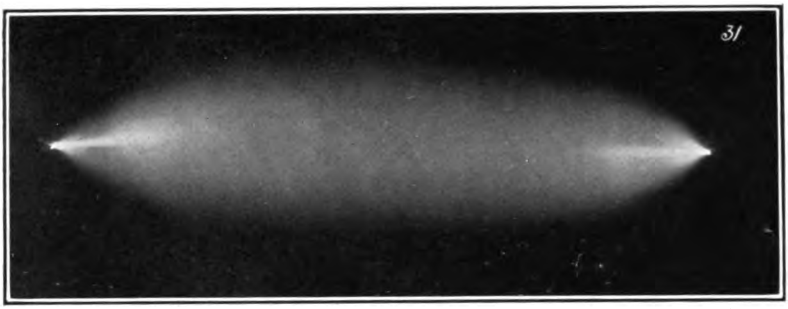


(1) Without stroboscope



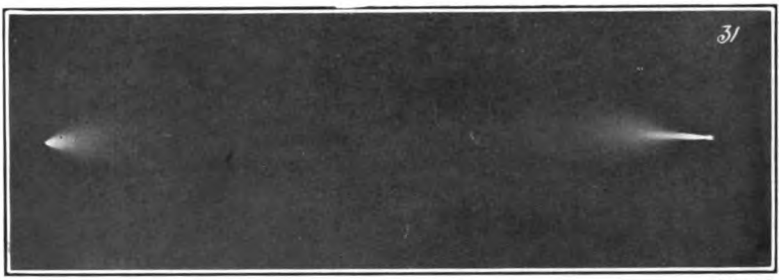
Left + (2) With stroboscope Right −

FIG. 30—CORONA BETWEEN COPPER NEEDLE POINTS—25.4 C.M. GAP—90,000 VOLTS



[PEEK]

(1) Without stroboscope—72,000 volts.

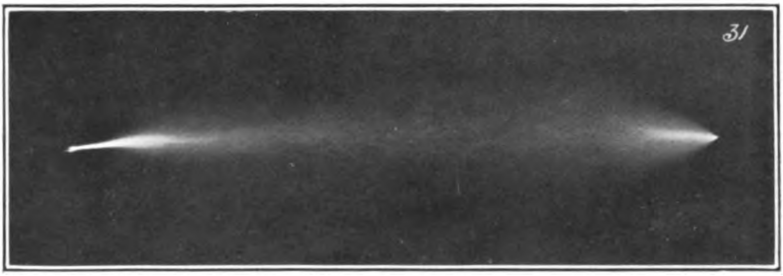


[PEEK]

Left — (2) With stroboscope—72,000 volts. Right +

[PEEK]

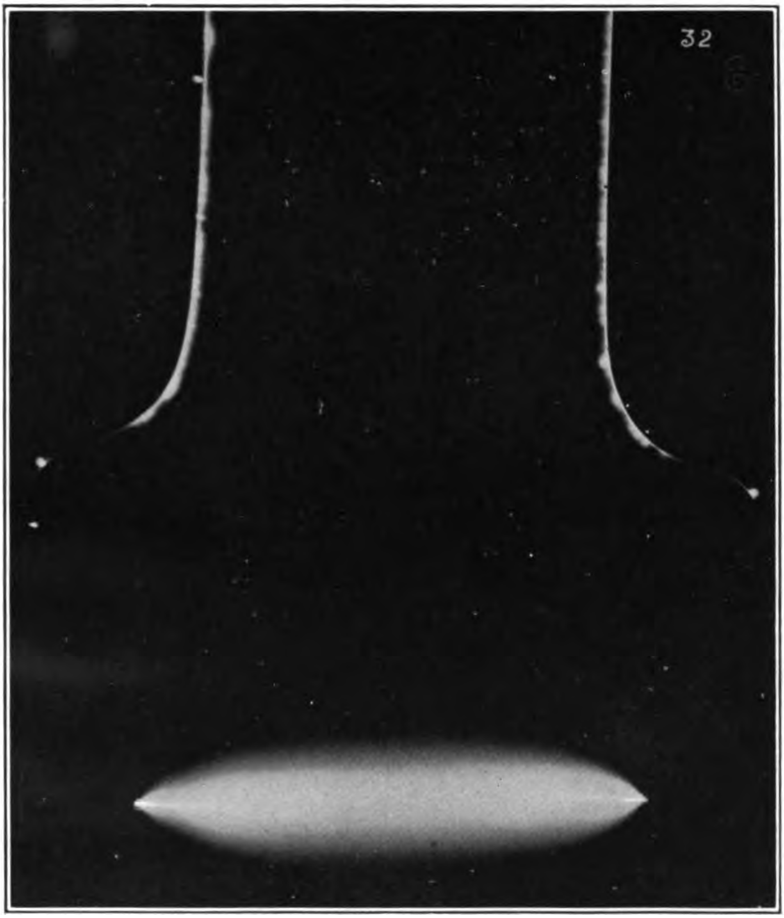
Left + (3) Stroboscope rotated 180 deg. Right —



[PEEK]

Left + (4) Same as (3) with voltage increased to 84,000 Right —

FIG. 31.—CORONA BETWEEN COPPER NEEDLE POINTS.
Spacing 20.5 cm.



[PEEK]

FIG. 32.—COMPARISON OF CORONA ON WIRES AND BETWEEN NEEDLES WITHOUT STROBOSCOPE.

Phosphor bronze wire, spacing 14.5 cm. Spacing of needles 18 cm. 71,000 volts.

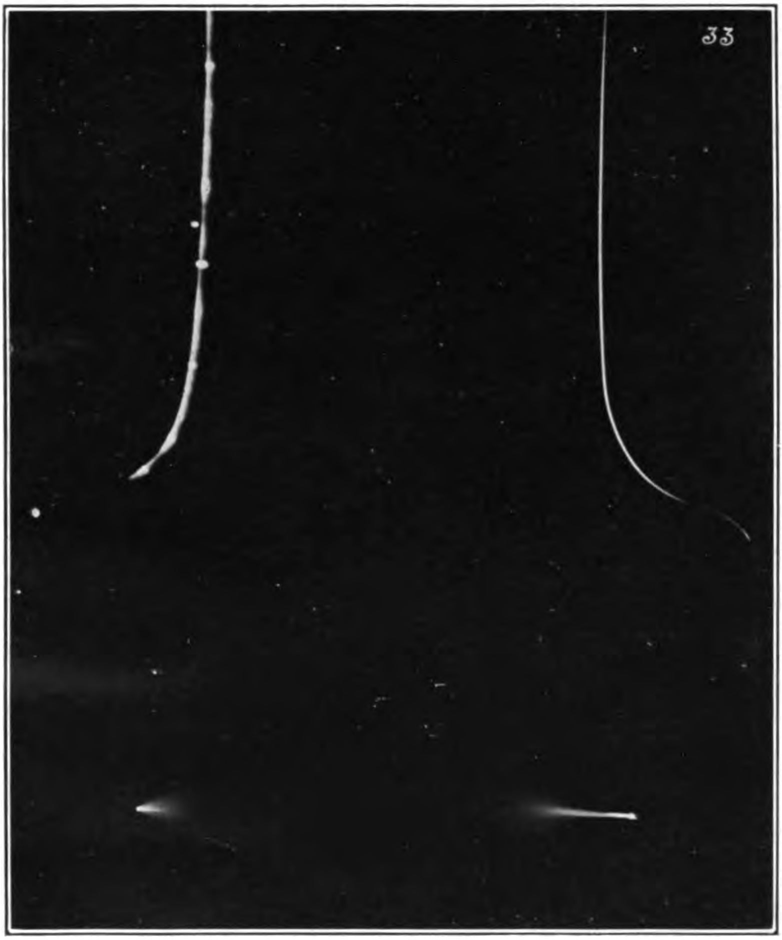
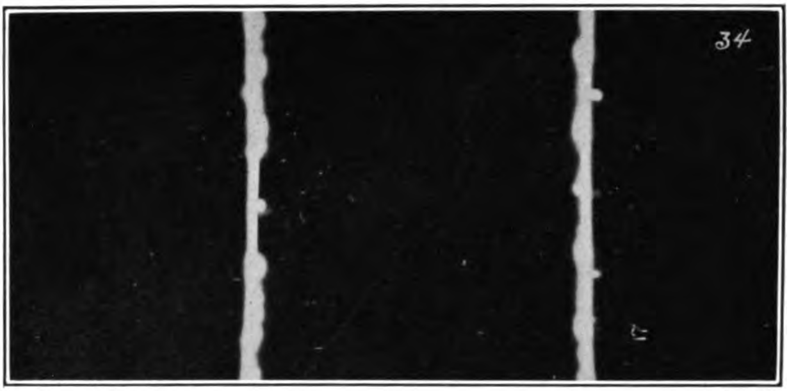
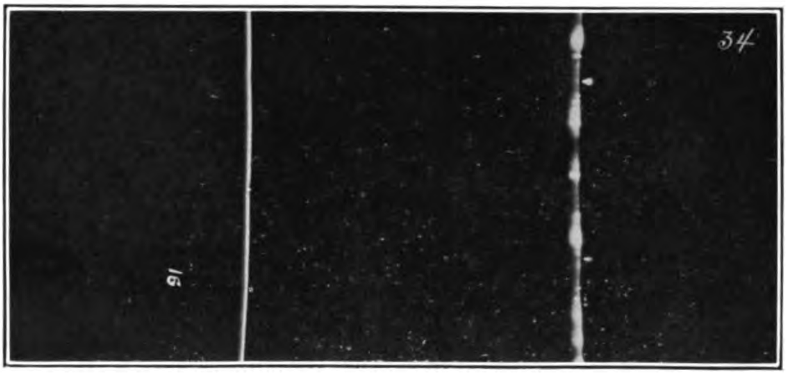


FIG. 33.—COMPARISON OF CORONA ON WIRES AND BETWEEN NEEDLES, WITH STROBOSCOPE.



[PEEK]

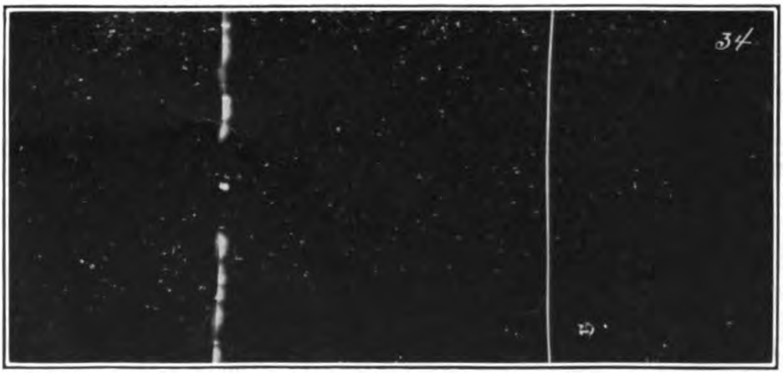
(1) Without stroboscope.



[PEEK]

Left + Right —

(2) With stroboscope.

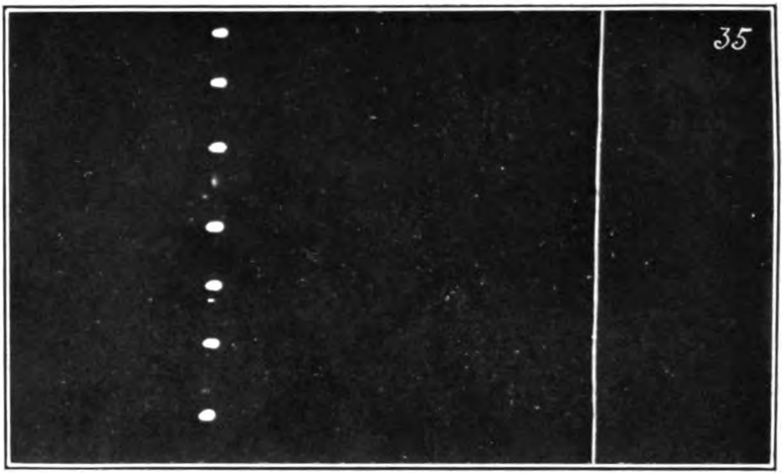


[PEEK]

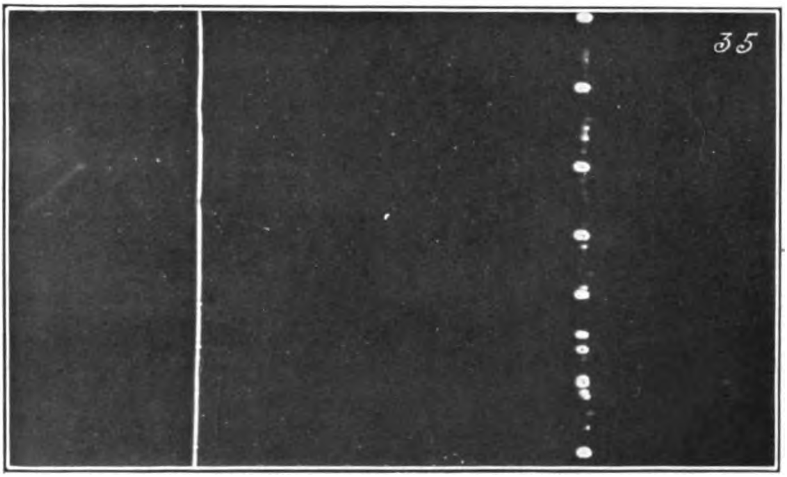
Left — Right +

(3) With stroboscope rotated 180 deg.

FIG. 34.—CORONA ON PARALLEL WIRES.
No. 13 B. & S. wire—spacing 12.7 cm.—82,000 volts.



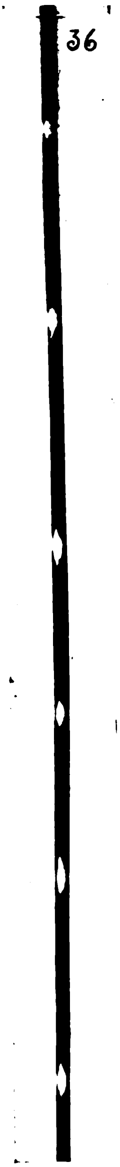
(1)



(2)

FIG. 35.—CORONA ON PARALLEL WIRES.

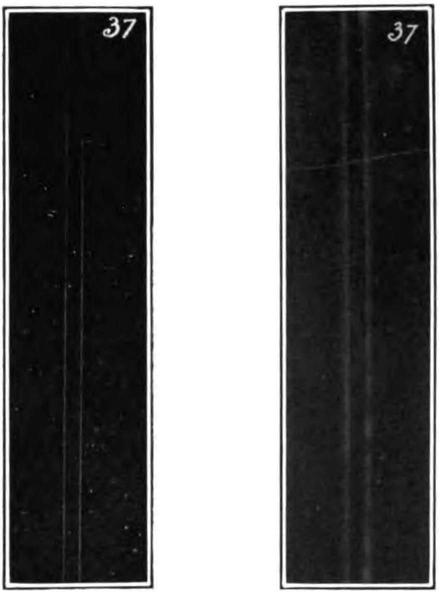
Iron—first polished and then run at 120,000 volts for two hours to develop spots. With stroboscope. Photographs taken at 80,000 volts. Diameter 0.168 cm. Spacing 12.7 cm.



[PEEK]

FIG. 36.—SECTION OF WIRE (FIG. F)

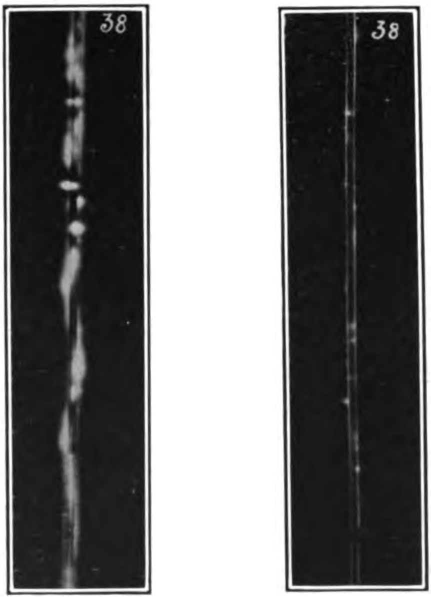
No volts. Bright spots show position of negative "beads"—enlarged scale.



Left — [PEEK] Right + [PEEK]

FIG. 37.—POLISHED BRASS ROD.

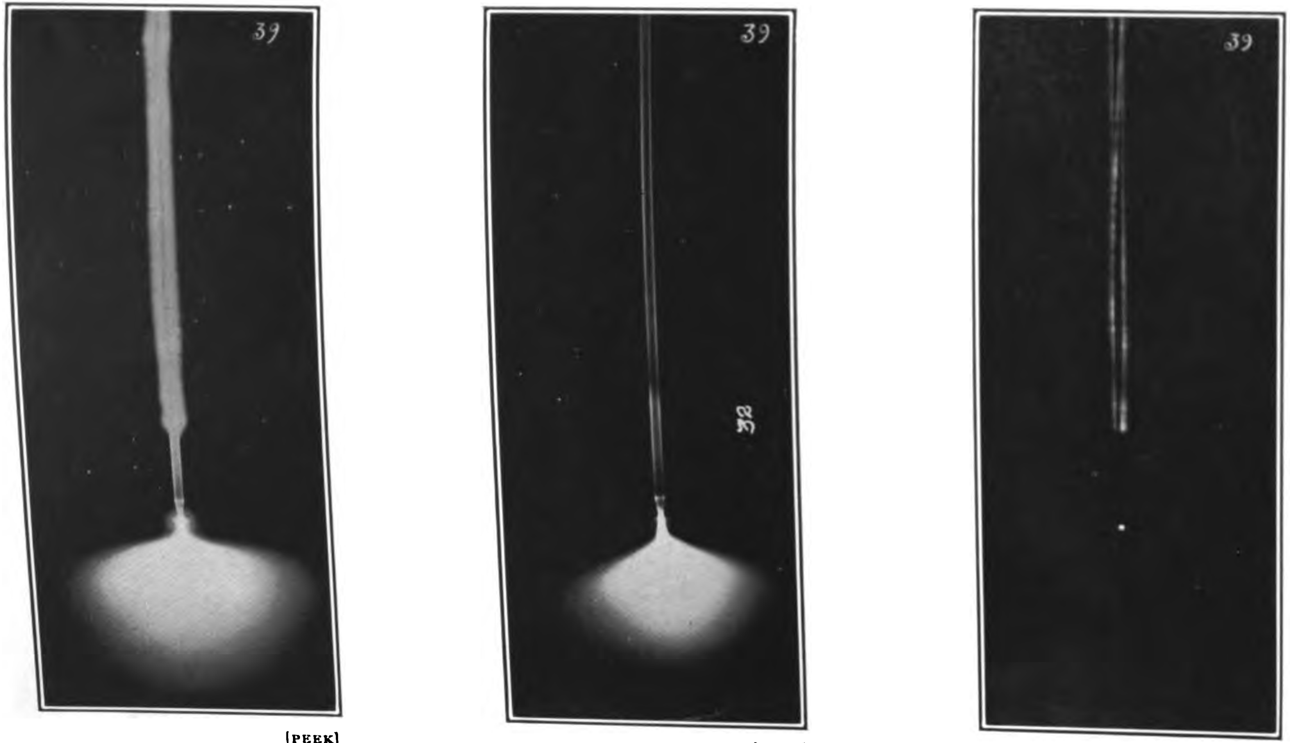
Diameter 4.75 cm.—spacing 120 cm.—150,000 volts. Note that negative "beads" are just starting to form.



Left — [PEEK] Right + [PEEK]

FIG. 38.—COPPER WIRE.

Diameter 0.26 cm.—spacing 120 cm.—200,000 volts. Polished at start—note negative apparently following spiral "grain" of wire.

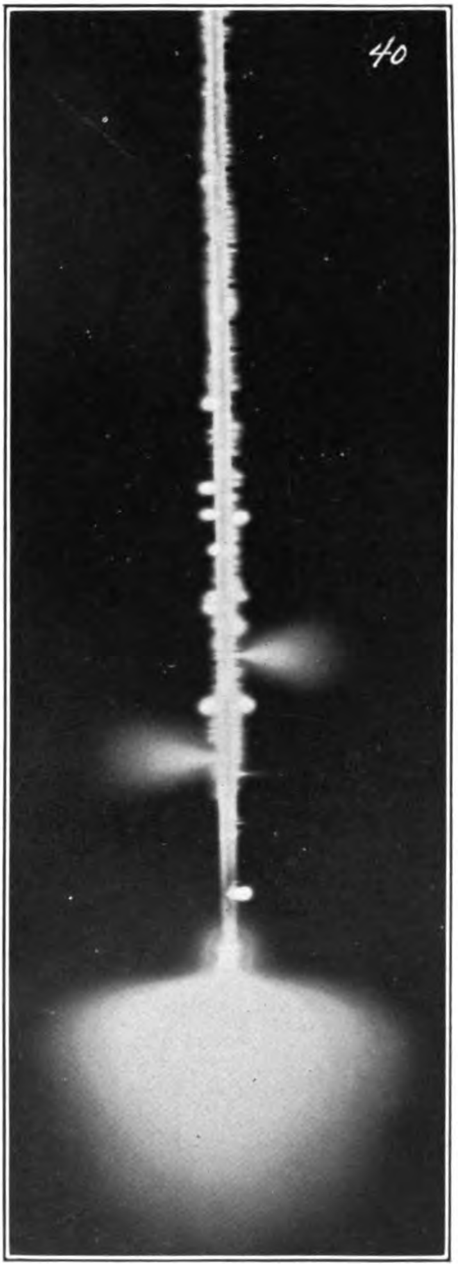


[PEEK]
(1) Without stroboscope.

[PEEK]
(2) With stroboscope—Pos.

[PEEK]
(3) With stroboscope—Neg.

FIG. 39.—ONE OF TWO POLISHED STEEL RODS POINTED AT ENDS.
Diameter 0.325 cm.—spacing 120 cm.—180,000 volts.



[PEEK]

FIG. 40.—ONE OF TWO PARALLEL STEEL RODS POINTED AT ENDS (DIRTY).

Without stroboscope.

[PEEK]

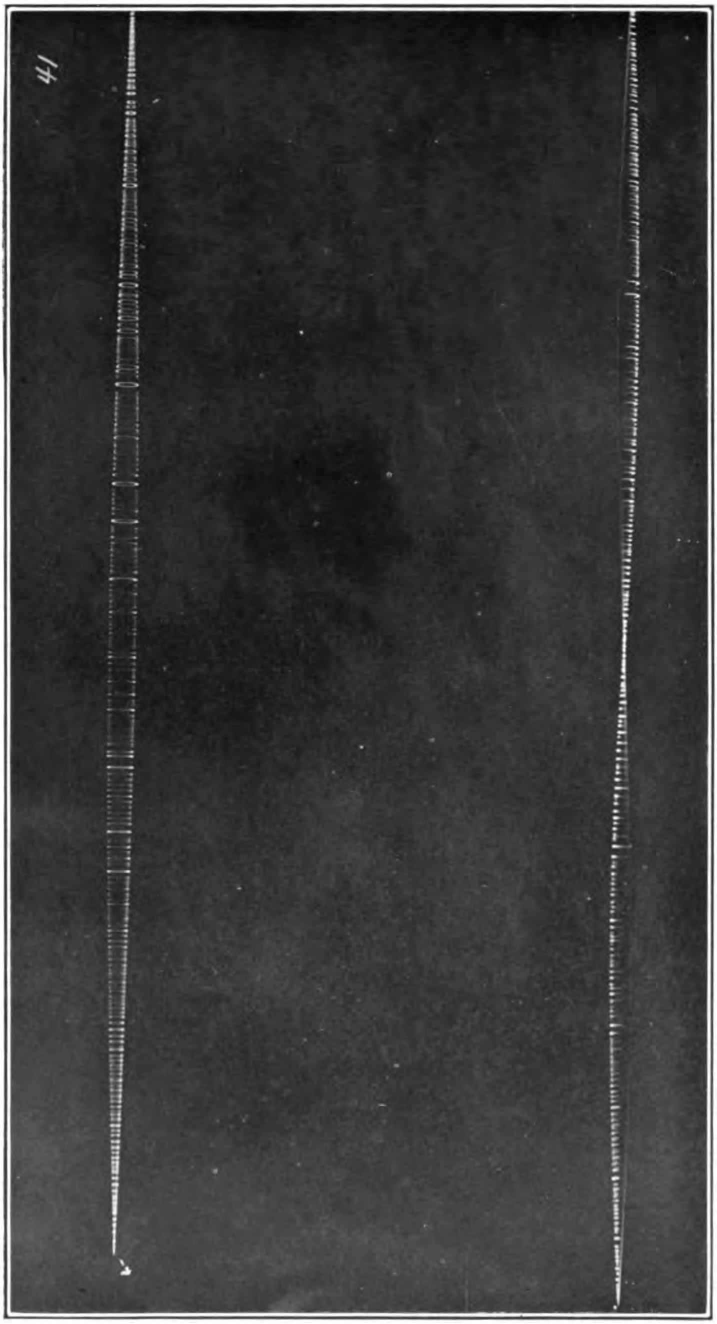


FIG. 41.—MECHANICAL VIBRATION OF TWO PARALLEL WIRES.
Length 147 cm.—spacing 49 cm.—diameter 0.00254 cm.—150,000 volts

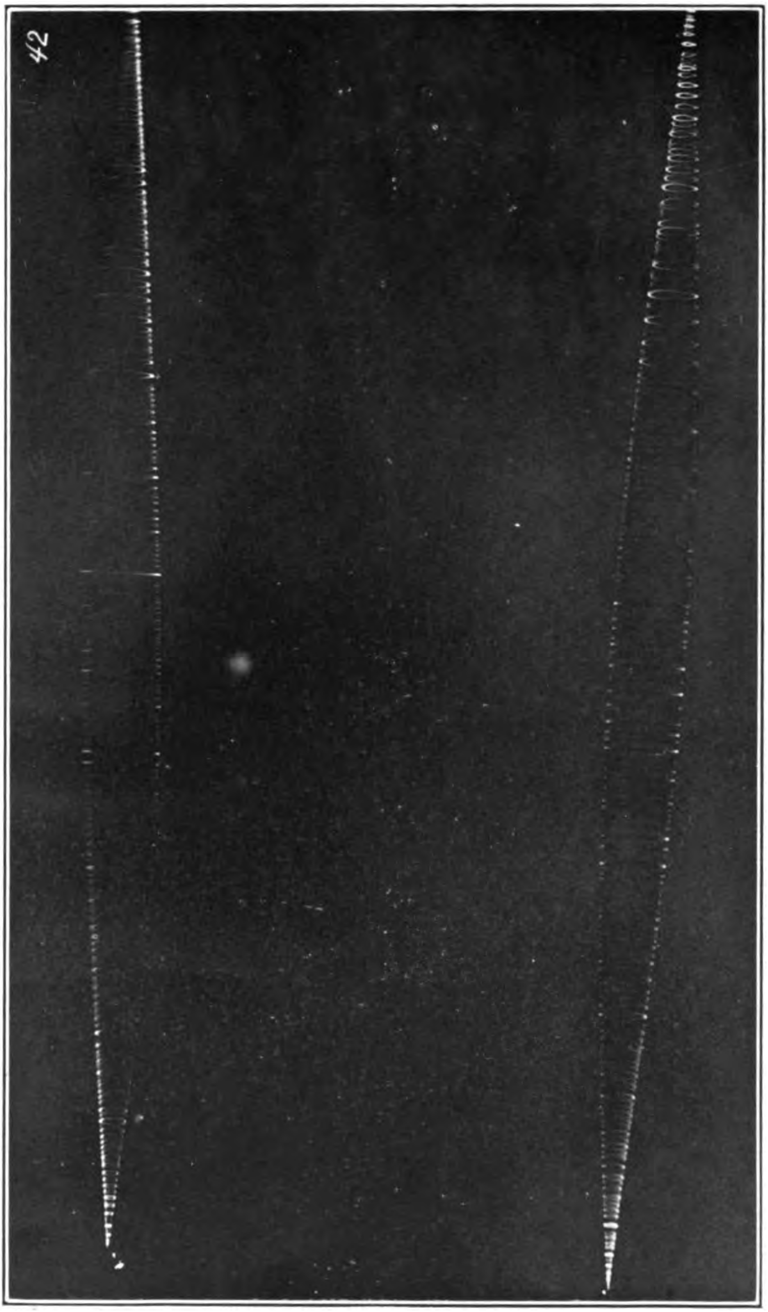
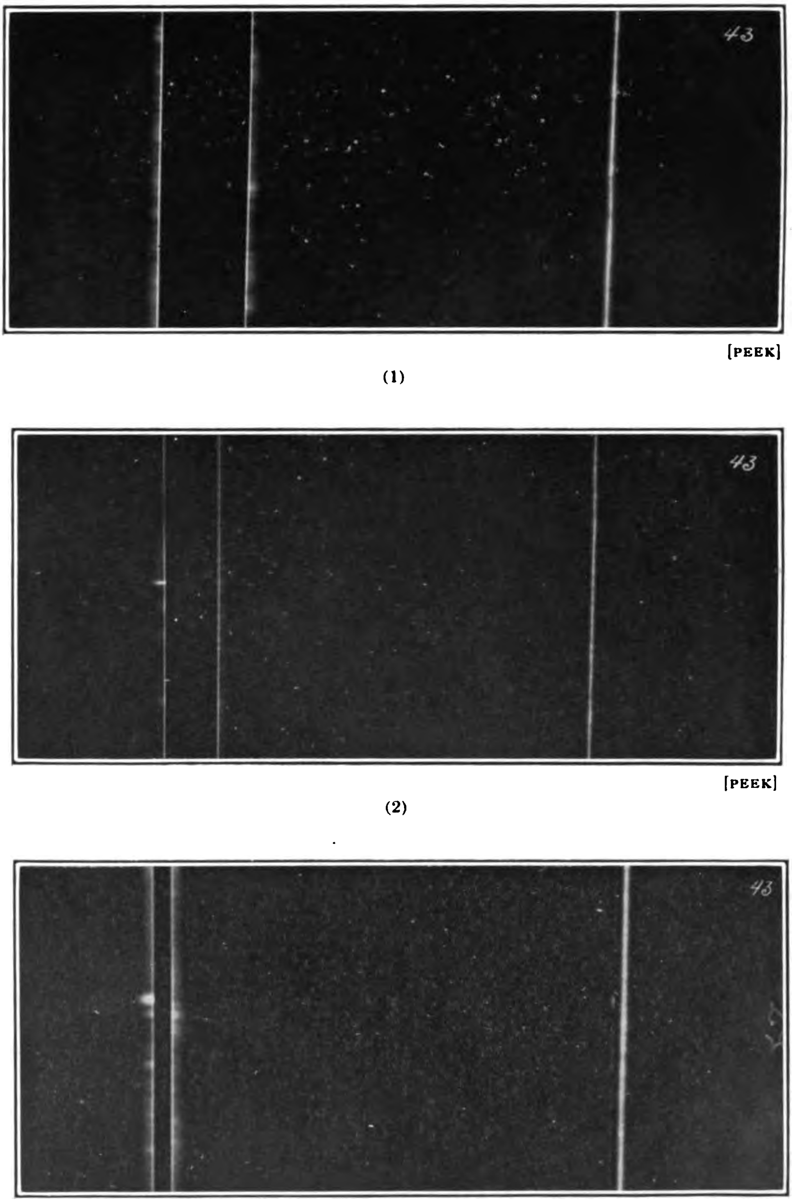


Fig. 42.—Mechanical Vibration of Parallel Wires.

[Peek]



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(2)

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(3)

FIG. 43.—PARALLEL WIRES AT SAME POTENTIAL, WITH DIFFERENT SPACINGS.

At left, view perpendicular to plane of wires.
At right, view in plane of wires.

giving the effect of a single discharge completely across between the conductors.

In the hope of throwing further light on the discharge and loss mechanism an investigation of corona and spark was started with the help of the stroboscope. This investigation is still being continued.

A needle gap was first arranged across the transformer with a high steadying resistance. The impressed voltage was adjusted until corona *appeared* all the way between the conductor as in Fig. 30 (1).

Examination of this was then made through the stroboscope which was so set that the left needle, Fig. 30 (2), was seen as positive, and the right as negative. To the eye, the discharge from the positive needle has a bluish white color and extends out a considerable distance, the negative appears as a red and hot point. This confirms the speculation made above. Thus, the discharge always starts out from the positive toward the negative. Fig. 31 (1) is the discharge as it appears without stroboscope, 31 (2) with right needle as positive, 31 (3) with stroboscope shifted 180 deg. to show left needle as positive. In 31 (4) the stroboscope has the same position as 31 (3), but the voltage is higher, and many fine " static " sparks can be seen. Note that the discharge gives one the impression of a spray issuing from the positive under pressure and being collected in at the negative.

If voltage above the visual corona point is impressed on two parallel polished wires a more or less even glow appears around the wires. After a time the wires have a beaded appearance. On closer examination the beads appear as reddish tufts, while in between them appears a fine bluish white needle like fringe. On examination through the stroboscope it can be seen that the more or less evenly spaced beads are on the negative wire, while the positive wire has the appearance, if not roughened by points, of a smooth bluish white glow. At points the positive discharge extends out at a great distance in the form of needles; it is probable that it always extends out but is not always visible except as surface glow. Thus, the appearance of beads and fringe to the unaided eye is really a combination of positive and negative corona. In Figs. 32 and 33 two wires are placed close together at the top. The bottom is bent out and needles fastened on. Fig. 32 is without stroboscope. Fig. 33 is taken with stroboscope set to show positive right and negative left. Thus, positive and negative coronas for points and wires are directly compared. Fig. 34 (1) is taken without the stroboscope, (2) with right negative, (3) with stroboscope shifted 180 electrical degrees to show the right positive. Fig. 35 (1) shows the left wire negative and right positive. These wires were, at the start, highly polished. At first corona appeared quite uniform, but after a time under voltage the reddish negative tufts separated, more or less evenly spaced as shown. 35 (2) is the same with stroboscope shifted 180 degrees. Fig. 36 shows a section of this wire photographed on an enlarged scale without voltage. The bright spots are still polished and correspond in position to the negative tufts. The space in between is oxidized. Thus, the negative discharge appears to throw metal or oxide from the surface at discharge points. This takes place with either copper or iron wire.

Fig. 37 shows positive and negative wires widely spaced to get uniform field. A close examination of the negative shows beads about to form. Fig. 38 shows a similar pair of conductors. The negative in this case has formed a spiral, apparently following the grain twist of the conductor.

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The corona loss seems to be in the form of a " conduction " across from positive to negative, always starting from the positive conductor—thus starting alternately at each half cycle, from one conductor, then from the other. The voltage point on the wave at which corona starts is higher than where it stops. Work is also being done to determine the relative position on wave at start of positive and negative coronas.

Many of the stroboscope data to date are given here as taken and without speculation. It is hoped that considerable light will be thrown on the mechanism of discharge and loss by this investigation.

XI. MECHANICAL VIBRATION OF CONDUCTORS AND OTHER PHENOMENA

Over a year ago a pair of 20-mil steel conductors, 500 feet long, were strung at about 10 ft. spacing, for power loss measurements. It was noticed at high voltage that the conductors vibrated, starting with a hardly perceptible movement, which in a few minutes had an amplitude of several feet at the center of the span. Generally one wire vibrated as fundamental, the other as third harmonic. The period of the fundamental in this case was about one per second.

Figs. 41 and 42 show this condition repeated in the laboratory on short lengths of conductor. In Fig. 41, one wire is vibrating as the fundamental, the other as the second harmonic. The motion is rotary. For the wire with node in center, Fig. 41, it is extremely interesting to note that for about one-half of the rotation the wire appears very bright, for the other half rotation the wire is much less bright. This seems to mean that each part of the wire is rotating at the power supply frequency—60 cycles per second. Hence it has the effect of the stroboscope, and for part of the rotation there is always negative corona and for the other part always positive corona.

Fig. 43 shows two parallel wires connected to the same side of the transformer, and at a constant spacing S of 120 cm. from the conductors of the opposite line; 180,000 volts is impressed between lines. Both front and edge view is shown. (1) shows the two wires of same potential 2.54 cm. apart. (2) shows the wires 1.27 cm. apart and much less corona than on (1). (3) shows the wires very close together, and that the corona has increased again. The critical voltage is maximum, therefore, for spacing somewhere between (2) and (3). Note that the coronas are repelled out and the space between the two wires is dark. A somewhat similar thing takes place on a stranded cable where the critical voltage is much higher than the critical voltage of a single strand, but somewhat lower than a solid conductor of the same outside diameter.

Fig. 43 means that when conductors of a given polarity are placed near other conductors of the same polarity the critical voltage is increased, also that there is a certain best arrangement of conductors for maximum e_v.

XII. General Remarks

While the experiments and deductions included in the present paper throw a great deal of additional light on the mechanism of corona formation and loss there is still considerable work to do both from an experimental and theoretical standpoint. It was thought best, however, in order to make the results most useful, to put them in the hands of other investigators as soon as obtained, and in their present form.

Extensive experimental investigations are still being planned and carried on. These have a bearing on theoretical work done, but not included here. Of special interest will be the effect of frequency on power loss and visual corona, over a very wide range, corona at continuous impressed volts, etc.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 26, 1912.

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(*Subject to final revision for the Transactions.*)

THE PROBLEMS OF INTERIOR ILLUMINATION

BY BASSETT JONES, JR.

The practise of illuminating engineering as a separate profession is a recent development of applied science. So short a time ago as 15 years there was little if any room or need for such work, and the " art of illumination " was largely a matter of guess work, precedent, and simple attempts to produce artificial light with little attention given to its distribution from the standpoint of economy as that word is understood today.

Within the last decade we have seen remarkable strides in the development of illuminants to meet the enormous demand for means of efficiently producing brilliant illumination. This demand is largely due to the commercial pressure of the times which requires that we shall do a large part of our work and take practically all of our pleasures after dark.

It has been found that the character of illumination has a direct influence on the efficiency of work, and efficiency, in the broad sense, being the pass word of the period, it naturally follows that any profession, the practise of which can do much to improve economical conditions will find a large demand for its product.

The economical production of artificial light, depending, as at present, generally upon the raising of solids or gases to exceedingly high temperatives has required a parallel development of auxiliary devices to protect the eye from injury.

The design of illuminants, generally following upon the results of laboratory experiments and research has produced devices, the sole object of which is as a rule the economical production of light. Until very recently the difficulties encountered in the commercial manufacture of illuminants has precluded any defi-

nite attempts at design for given distribution of light flux, and this has opened a wide field for the manufacture of reflectors to redistribute the flux properly for the varied sorts of work to be done by its aid.

The work of the illuminating engineer is, then, the design of such arrangements of illuminants as will most economically meet the demand for properly distributed light. In attacking any specific problem he must consider, first, the kind of work to be done by artificial light, second, the distribution of light flux that will make it possible to do that particular work best under such abnormal conditions as the limitations of his resources impose, and third, the character and arrangement of illuminants that will most economically produce the light required.

So much for the general aspect of our subject. Specifically I propose to devote the remainder of this paper to the consideration of certain phases of the problem of interior illumination, where the interior is of such architectural character as to demand in the design of its lighting equipment more than mere engineering considerations, and for the reason that an enormous field for this kind of work is rapidly developing itself. The problems that arise during the design of such illuminating schemes are varied, interesting, and their solution often taxes to the uttermost the knowledge, imagination and ingenuity of the engineer.

Those who are in touch with the philosophy of our time know that the word "efficiency" has acquired a very great importance in fields of activity into which energy, as we understand the word, does not enter. "Human efficiency," "Social efficiency," etc., are expressions the use of which is increasing and this broadening of the concept has had a retroative effect on the engineering profession until today, we frequently hear the engineer talked of as a social servant. His work is efficient when it redounds to the benefit of society and this, whether or not his designs are worked out with regard to maximum energy efficiency. As a matter of fact one's work is efficient when, with a minimum of means, one succeeds in accomplishing what one set out to do. But the accent is always on the success.

It does not matter whether what is accomplished is the generation of 50,000 kilowatts at Squeedunk Falls and its transmission to Bisonville, the construction of a hundred story building, the ornamentation of a wall, the carving of a marble Venus, or the salvation of lost souls, the same rule applies, and, by the same token, it is, within reason, the result rather than the means by

which the world will gage such work. You, as engineers, may sit in judgment upon the fractional percentage avoidable loss in the Squeedunk-Bisonville line, but the citizen of Bisonville judges only by the constancy and general satisfaction of the service.

So, in the artificial illumination of interiors such as we shall study, the gage of efficiency can only be applied when we appreciate and understand the results accomplished whether these results be the proper illumination of the working areas or attainment of proper shadows and color values in the architectural design or both. Usually both results must be obtained. Hence this complexity of the problem.

It has generally been the custom to rate the efficiency of a lighting equipment by the ratio of light flux received on a plane determined at so many inches above the floor to the light flux generated. The arbitrary and unnatural results obtained are best criticised by the following considerations.

Such a method of determining efficiency counts as a loss all of the light employed in producing beautiful effects in fixtures and lost by absorption in the pigments used in decorating the walls and ceiling. The light so employed in properly obtaining effects is useful in the sense that it does what is required of it. It does not follow because the light used in setting forth the design of a library is not directly concerned with the actual business of the room, that the lighting equipment is inefficient. In fact only a small portion of the generated flux need be used for reading and still the system be highly efficient, since it makes the room effective and pleasant to see and to be in whether one reads or not.

So too, in an ornate banking room only a very small proportion of the generated flux may be employed in illuminating desks or other places where the work of the bank is done provided such places are in themselves properly lighted, and still the illuminating efficiency be very high when properly rated.

It is quite useless to have beautiful things unless one can see them, and that illumination which properly sets them off in true value as to perspective, shadow, and color is correctly designed no matter how much energy is necessarily and purposefully used in obtaining the correct results.

In fact, the work to be done by any such lighting arrangement is not only to enable us to see to do our work with ease and comfort, but also to make the interior pleasant to the senses

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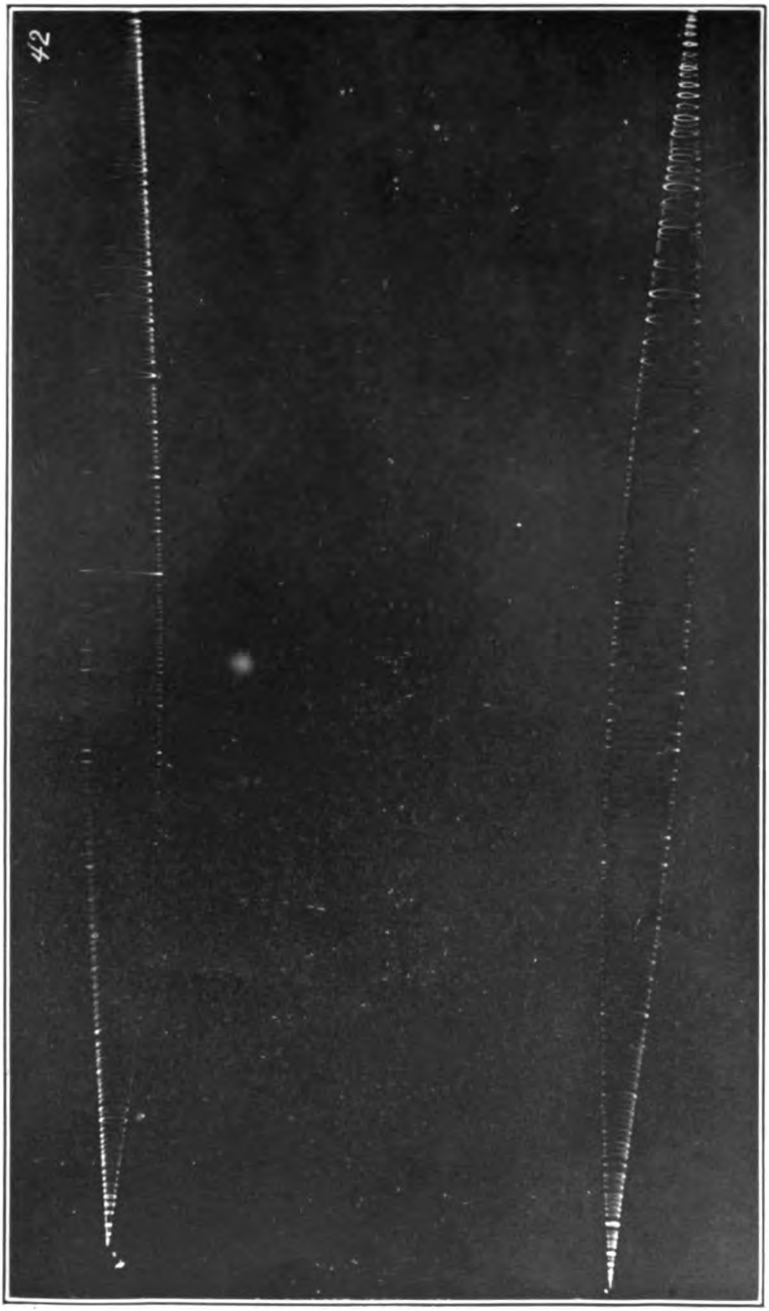
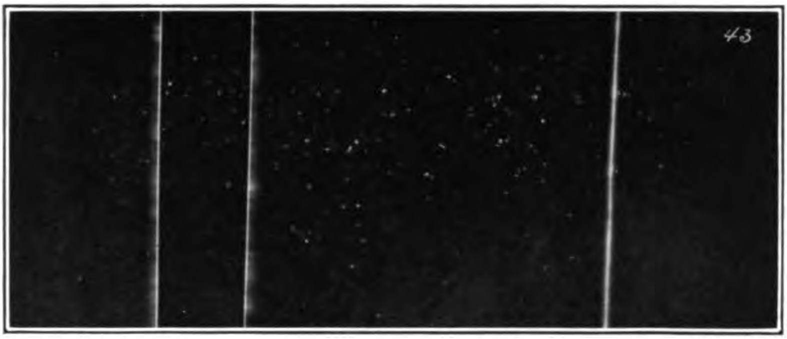


Fig. 42.—Mechanical Vibration of Parallel Wires.



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At left, view perpendicular to plane of wires.
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Such a method of determining efficiency counts as a loss all of the light employed in producing beautiful effects in fixtures and lost by absorption in the pigments used in decorating the walls and ceiling. The light so employed in properly obtaining effects is useful in the sense that it does what is required of it. It does not follow because the light used in setting forth the design of a library is not directly concerned with the actual business of the room, that the lighting equipment is inefficient. In fact only a small portion of the generated flux need be used for reading and still the system be highly efficient, since it makes the room effective and pleasant to see and to be in whether one reads or not.

So too, in an ornate banking room only a very small proportion of the generated flux may be employed in illuminating desks or other places where the work of the bank is done provided such places are in themselves properly lighted, and still the illuminating efficiency be very high when properly rated.

It is quite useless to have beautiful things unless one can see them, and that illumination which properly sets them off in true value as to perspective, shadow, and color is correctly designed no matter how much energy is necessarily and purposefully used in obtaining the correct results.

In fact, the work to be done by any such lighting arrangement is not only to enable us to see to do our work with ease and comfort, but also to make the interior pleasant to the senses and to make its beauty visible. The frescoes of St. Peter's are wasted unless they can be seen and for this purpose the " working plane " is on the ceiling and not near the floor.

These remarks recall to the writer a review of some of his work in which the curious statement was made that " the efficiency was remarkably high (about 25 per cent) when one considers the decorative character of the illumination."

I presume the reviewer considered that since the interior was an auditorium the working plane was somehow at the level of the programs. Apart from the question as to the existence of programs, is it not obviously ridiculous to ignore the light flux used to set off the ceiling, which happened to be the most important architectural feature of the room, and the elaborate and interesting color scheme of which the light sources themselves, their color and their intensity, formed a part?

As a matter of fact can such an illuminating system be rated at all in terms of energy efficiency? Obviously, it cannot be so rated, and the term has no meaning when applied. The difficulty is to distinguish between energy efficiency properly speaking and general efficiency which refers to the relation of end to means. Perhaps it would be better to rate such illumination in terms of effectiveness for, of course, we are dealing with a subject that bids fair to become a fine art. But in so doing we are introducing that indeterminate factor, personal taste.

Evidently one must come to judge such work free from the prejudices borne of narrow technical training. Appreciation of the beautiful must be our starting point.

But it is necessary for the engineer engaged in the design of lighting equipments of this character to have some basis of comparison. And for this purpose the arbitrary rating in terms of flux received on a certain plane may serve well enough. This will, at least, isolate that part of the illumination concerned with utilitarian ends.

The problems of interior illumination are now evident. The engineer must be able to grasp and appreciate the effect desired, and to so devise the equipment that this result will be accomplished with as little outlay and running cost as possible. He must understand the relation of shadow and color to design so that the lighting arrangements will not warp or destroy the value of the architectural treatment and ornament. For, as I shall later show, the importance of shadow and color is primary.

The engineer must know sufficient about color, as such, and about pigments, to discern beforehand just what effect any particular tone or intensity in the light will have in altering the color scheme, for both color and intensity in light have marked effects on colored pigments, and these effects vary with the character and saturation of the pigments. Thus the color of saturated pigments or pigments pure in color, remains true in tone under variation of color in the illumination, varying only in luminosity, while, under similar conditions, unsaturated pigments, or pigments mixed with white, vary widely in color.

Under low intensity of illumination the cold colors, blue-green, blue and violet are more luminous than the warm colors, red, orange and yellow, while under high intensity of illumination the results are reversed.

The relative importance of the colors in the ornamental treatment may then be variously altered by the character of the illumination. Since it is rarely possible to determine the color scheme only for artificial light, it must be subject to such alterations of greater or less extent and the engineer must so select and arange his illuminants that the change will not be injurious or productive of as little injury as possible.

The possibility of interestingly modifying the character of the color ornamentation by modifications in the color of the illumination opens up a remarkable field for the display of ingenuity and good taste. This phase of the subject is almost an art in itself.

Again, shadows constitute an important means of setting off relief design. Such designs are, in fact, little more than arrangements in light and shade, so that any extensive alteration of the shadows in direction, extent, or luminosity, will usually constitute a corresponding alteration in the effect of the design. The engineer must therefore see to it that the shadows, usually essentially altered by artificial light are changed in such a fashion as to produce an interesting effect. Reversal of shadows may reverse the apparent projections in the relief.

It is obvious, then, that where the architectural effects are produced by relief ornament, the apparent flattening of such ornament by excessive diffusion of light may have a very harmful effect. This is particularly true of Gothic design in which the characteristic is emphasized by deep reveals and returns producing deep and often black shadows with correspondingly accented high lights.

Of course, where loss of shadow is unavoidable, the design may be picked out in carefully selected unsaturated tints. During the day these tints, if carefully chosen, will be inconspicuous giving full play to shadow effects, while during the evening they may be accented by proper color or colors in the illumination.

Another consideration that in these days of unlimited indirect illumination requires careful attention is the balance of the design. For artistic effect, where should the emphatic illumination be thrown? The answer to this question lies entirely in a keen sense for proportion. Generally speaking interiors are lighted by daylight streaming through windows from the sky above the horizon, and the natural result is that almost all well conceived interiors are designed to present the best effect when the brilliant illumination is on or near the floor; the ceiling and upper parts of the room, lighted largely by reflected light, being subjected to relatively low intensity of illumination.

This result is natural, as we require to see well in that portion of the room we occupy and the sense of definiteness due to the bright illuminations in the lower planes gives a feeling of " bottom " to the area so lighted. The reversal of the effect, particularly when there is great contrast between the now brightly lighted ceiling and the floor produces a decided feeling of unbalance and lack of firmness. The ceiling acquires a prominence not warranted by its purpose. However, as we shall later point out, occasions may arise when the architectural design is such that the light may and should properly be thrown first upon the ceiling and then redistributed. But in all such cases great care must be taken to balance the effect by correct design of the equipment, and in nearly all such installations the intensities of illumination must be so low that the contrast effect is inconspicuous.

In the consideration of indirect illumination the question of the excessive loss through re-reflection from painted surfaces is frequently brought up. But such losses are commonly less than would ordinarily be expected, due to the fact that the coefficient of reflection of diffuse reflecting surfaces is higher the more diffuse the impinging light.

Lastly, we have the question of lighting fixtures, to consider, for, these must, as a rule, form a part of the room furnishing, be things of beauty both by day and by night, and being a part of the design, they must partake of the character of the design both in proportion and decoration and still execute the duty demanded of them.

So much for one aspect of our problem, although the discussion might be developed at great length. What has been said may serve to indicate how far-reaching and broad the subject is.

We now have an equally important series of problems to consider in the design of that part of the illumination concerned with the utilitarian purpose to which the interior is put. It is unfortunate that the limitations of architecture, and perhaps also the limited ability of architects, coincident with the limited ability of engineers, makes it impossible for the design of interiors, practically as well as theoretically, always to be suited precisely to their purpose as human conveniences. If we have the money to spend we are prone to demand that our houses as well as our working places be merely beautiful in themselves, and, as an example, we find ourselves frequently called upon to cope with a problem in illumination where the light that will serve to set off the beauties of the design is totally inadequate as a means of enabling us to use the structure properly.

Rarely, and generally by accident, the two requirements may be made to coincide. Sometimes the illumination designed for one purpose may be used to reinforce or be superimposed upon the other. Frequently the two must receive independent treatment and the result be so arranged as not to be unpleasant.

The safest method of attack is to solve each problem separately and then cast around for some means of bringing them together.

From the utilitarian standpoint we have first to consider the eye. Arrangements which produce strain, fatigue, and other injuries must be avoided. Low intrinsic brilliancy of exposed light sources and shading of sources possessing high intrinsic brilliancy are imperative. The equipment must be so designed that images of the otherwise well shielded light source may not be reflected to the eye from surrounding surfaces of objects. The portions of the mechanism for vision—the iris, the eye-brow—must be able to perform their functions normally. The maximum intensity of light must be concentrated upon the work and by variations in intensity between the light on work and on surrounding objects the muscles of adjustment must be given opportunity for exercise. Nothing in lighting can be more unfortunate than an equal distribution of intensity throughout as then the muscles that adjust the iris are kept in a fixed position and we should find ourselves much in the same condition of fatigue as though we were compelled to hold one arm out straight for a considerable period of time.

It is better that the change in intensity from the work to surrounding objects be downward rather than upward as under such conditions the eye is given frequent rests. In libraries and reading rooms it is well if this change be relatively great, but not so great that the iris, once having opened wide, is not given a chance to readjust itself within reasonable limits when the eye is once more turned toward brightly lighted areas. In general, variations in intensity throughout an interior automatically produce normal exercises of the optic muscles. Further, the reflecting devices used to concentrate illumination upon the work must be so disposed and designed that light rays directly reflected from the work will not strike the eye.

The color of the light may have a very marked effect upon the ease and comfort with which work can be done. The value of the intensity certainly does have such an effect and must be carefully determined in each case by experiment and test.

These and numerous other similar problems must be studied and solved before we are even prepared to calculate the total quantity of light flux required and so determine the amount and distribution of energy to be used.

It can readily be seen that in many cases of interior illumination the sum total effect of the variables which have to be independently determined for each instance, usually by trial, may greatly exceed in amount the sum total effect of the constants that, with reasonable accuracy, can be predetermined. In this lies the principal difficulty in the way of the development of the art along any exact lines. Another difficulty is the lack of definite information so generally evident in the early stages of all progress.

Complete and useful values of reflection and diffusion coefficient from various surfaces variously colored, and subjected to various arrangements and color of light; data as to the spectral composition of the light from standard illuminants; sensitiveness curves for color in the light of illuminants; exact data on color changes and contrast effects; studies of pigments; spectral composition and measurements of the light obtained from various illuminants transmitted through color screens; all of these and many more lines of inquiry must be followed out before any great exactness can be introduced into the solution of such lighting problems as we are considering.

There are needed also the results of careful and authoritative research into the subject of what has been called "visual acuity;" that is, the effect of various light arrangements upon the ability to discern various kinds of objects with distinctness; this among other problems in physiological optics where much needed data is lacking.

The principal difficulty encountered in the attempt to give any fixed form to such data, is that the subjective elements, whose total effect is termed "the personal equation," are prominent factors in all judgments having to do with the measurement of the sensations of color and light. Such experiments are in reality attempts to measure and compare subjective activities themselves and thus, since the work approaches closely to the business of psychology, the method of inquiry must be largely the method of psychology.

Assuming now, that in any particular case, the engineer has attacked and solved the preliminary problems above briefly outlined. He is then in a position to determine with a greater or less degree of accuracy the total light flux required. It may be taken for granted that he has carefully studied the use to which the interior is to be put, has mapped out the working areas and has determined the average intensity and direction of flux over these areas. He has we shall presume, obtained from the architect information as to the general design, its character, detail, and color. He has probably prepared several schemes of illumination, the accomplishing of which has seemed practical, and these he has discussed with the architect until he has, at least, grasped the ideal embodied in the design. His imagination has enabled him to see the interior as the architect has seen it in his mind's eye, and so it must appear to the beholder when completed. The engineer is now in a fair way to achieve some measure of success.

The architect's details and, if possible, plaster models, having been studied by 'the engineer for shadow, the general direction of the light at various points required to lend visibility to the design may be determined.

The relative value of directed to diffuse light can be settled by noting the style of design, the relation of coarse to the fine relief, and the character of the detail within the shadows. The color of the light will be decided by a study of the color scheme the architect will employ.

Thus having established the intensity and direction of the light at various points, or over the various areas, of the design, the location of the light sources, primary or secondary, can be determined. Of course, in nearly every case, only an approximate realization of such ideal conditions can be achieved.

The location of the light sources thus having been fixed, the amount of flux to be generated, allowing for the character of the equipment imposed by the design, can be calculated with reasonable exactness.

For this part of the work three general methods are available, all of which are useful. These are, in order of development.

1. Point-by-point method.
2. Flux method.
3. Absorption method.

We shall devote a few words to each of them.

The *point-by-point method* employs the ideas of intensity and its direction. It attacks the problem in precisely the same way that is employed in calculations for intensity or potential gradient in the electric or magnetic field. The formulæ employed in the two problems are, in general, identical in form.

Given a light source having a certain radial distribution of intensity it is generally possible to calculate the intensity in any direction at any point in the light field. The method is often tedious but, particularly where shadows or glare by reflection is concerned, serve as an excellent check on the two remaining methods. Geometrical or graphical solutions as substitutes for analytical solutions are frequently simpler and equally useful.

Where surface sources such as skylights of considerable area or wall surfaces considered as secondary sources are concerned, the point by point method is generally useful in spite of complications.

The point-by-point method bears much the same relation to the flux method that calculations for intensity bear to calculations for flux density in the magnetic field.

In the *flux method* we either assume an average flux density over a given area to be lighted or find the average of the intensities at a number of points on the area, the intensity at any point being determined by the conditions of the problem or, with a given illuminant, calculated by the point-by-point method. The sum of the flux values calculated in this way over all the enclosing illuminated surfaces, allowing for absorption, etc., is the received flux. A certain part of it may be set aside as " useful flux " if desired. Generally it is all useful.

The received flux is also the generated flux when we add enough to allow for loss by reflectors, glassware, shades, etc. If we divide the generated flux by the flux generated per lamp in the type and size of lamp we desire to employ, we obtain directly the number of lamps required.

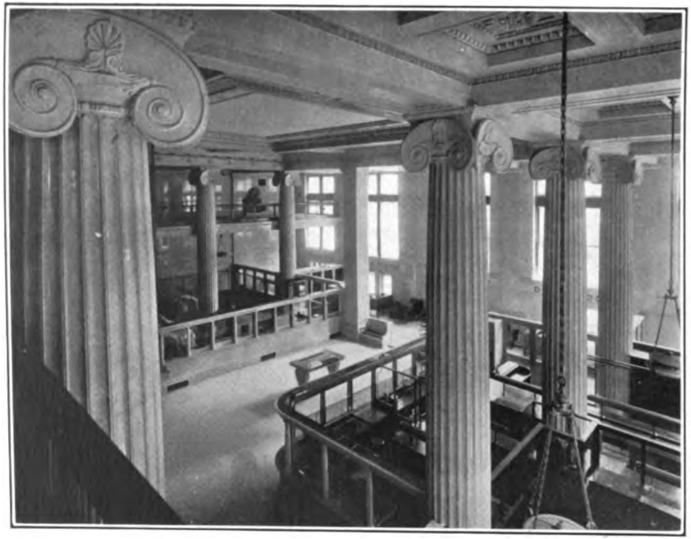


FIG. 1.—INTERIOR BY DAYLIGHT. [JONES]

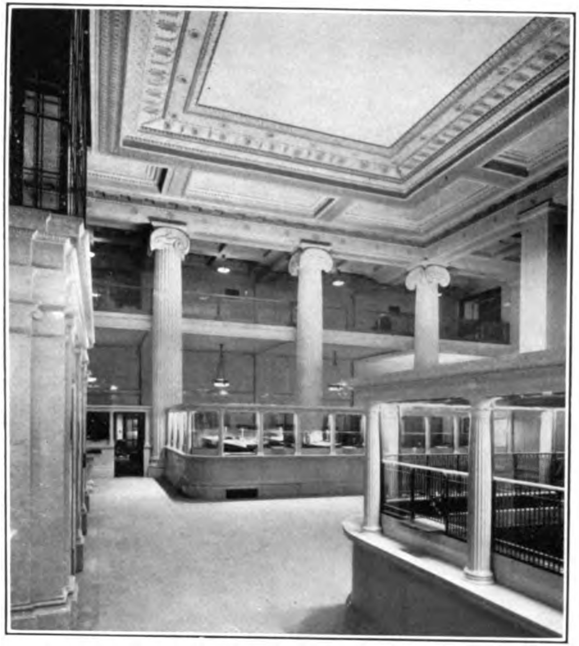


FIG. 3.—INTERIOR BY ARTIFICIAL LIGHT. [JONES]
Color Screens Removed. Shows Reversal of Intensities.

On the other hand, in using the ***absorption method*** we go upon the more logical and exact idea that the flux generated need only be that lost by absorption over the various enclosing surfaces lighted. Thus if we desire to light a surface to a given average flux density, we can apply to this average flux density the absorption coefficient for the surface, and count the result as the flux which must be generated in order to light properly the area in question. The results obtained by both " flux method " and " absorption method " are of necessity identical when properly applied.

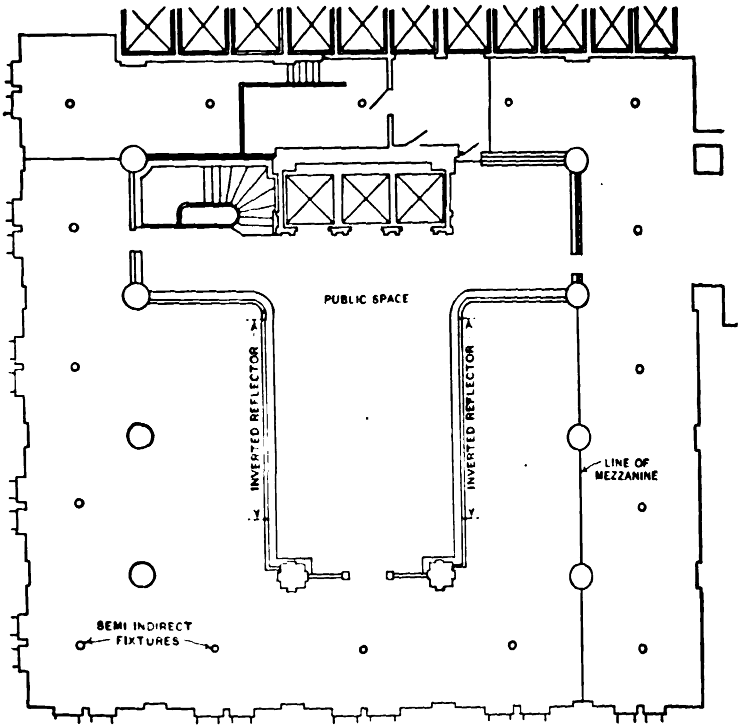


FIG. 2.—OUTLINE PLAN OF BANKING ROOM.

In order now, to give a concrete illustration of the application of these principles and methods I shall ask you to review briefly the studies and calculations carried out in the design of the lighting equipment of a banking room in New York city.

A general view of the room is shown in Fig. 1. Its plan is shown in Fig. 2. A view of the room taken at night by its own artificial illumination is shown in Fig. 3.

The room has an open central space and smaller bays on the four sides. A mezzanine is run along the north and west sides. The main ceiling height from the main floor level is 30 ft. The ceiling height below the mezzanine is 17 ft. and above, 11 ft. The floor area is variously divided into cages, conference rooms and offices, by wire mesh screens, marble partitions and wood and glass partitions 7 ft. 6 in. high. The main banking screen setting off the public space is of solid marble to the counter, and glass with marble columns and cornice above.

The walls, columns and column caps of the main room are of marble. This marble has a light reddish buff color highly polished Pavanella clair marble. The ceilings are of plaster. The ceiling of the central space is nearly flat with low relief ornament. The ceiling of each outer bay is divided by beams and soffits into four coffers in each of which is a plaster rosette. The ceilings under the mezzanines are flat. The color of the ceilings is generally a light reddish gray buff the ornament and mouldings being picked out in unsaturated tints of red, blue and yellow.

The general character of the architectural treatment is a refined classic based on the Ionic order. Delicate and beautiful mouldings and leaf ornament are used to set off the structural lines and proportions. A refined simplicity is the keynote of the design.

It will at once be seen from the illustrations that the large open central space gives the room, otherwise relatively restricted in area, an appearance of spaciousness. Therefore, it would not be proper to introduce hanging fixtures in this space. Indeed even if such fixtures might be used, the design of this part of the ceiling could not be made suitable to receive them without distinctly marring the effect On the other hand the outer bays seem to require some such furnishing if only to carry the line of the facia of the mezzanine floor. The crossing beams in the bay ceilings furnished a sufficient apparent structural support.

It so happened that the main banking screen was admirably suited in its position to receive such lighting devices as were required to light the central space, but since any effect of rows of illuminants would have been objectionable as lending too great a prominence to this feature of the design it was decided to employ indirect illumination, concealing trough reflectors in the cornice and leaving it to the fixtures in the outer bays to form the ostensible sources of light. For the lack of any such visible source is generally puzzling and productive of unfortunate psychological effects.

The location of the light sources so determined made it theoretically possible to produce good shadow effects. By proper handling of the side bay fixtures the deep ceiling coffers could be thrown into comparative shade and the ornament accented by so coloring the light thrown to the ceiling that the tinting in the coffer bottoms would be deepened leaving the rosette, soffits and colored mouldings in high light.

By confining the light thrown upward from the reflector in the top of the banking screen within the square defined by the beams framing the open central ceiling space as shown in Fig. 4, and by proper adjustment of the light near the sides of this space after the reflectors were installed it would seem possible to prevent any reversal of shadow on the column caps and architrave mouldings. The colors of the ceilings could be interestingly accented by the use of color screens in these reflectors.

So much for the upper planes of the room. But the bottom of a room is the floor, and the final adjustments must be such that the principal variation in intensity is inverse with regard to the height—not directly so, but in some multiple thereof that will produce the most suitable gradation. Thus, if i_f be the intensity near the floor and h the height, we may express this effect by writing

$$i = k \frac{i_f}{h}$$

where i is the intensity or, flux density of illumination at the distance h above the floor. The value of k is always such that i diminishes as h increases. In the room in question k should have a value of approximately 2, for, by experiment, this gradation seemed to produce the most satisfactory results.

We have a difficulty here, for, having selected an indirect system in general, our gradation is reversed. We can somewhat overcome this by so arranging our side bay fixtures that they will throw a large volume of light downward in a broad distribution. As we have said before they must also throw light upward. But now we meet two requirements that are dominant. First, the fixtures must be of the style and proportion suited to their location. Second, their intrinsic brilliancy must be low. The first requirement determines their size, the second requirement taken in conjunction with the first determines the total light flux these fixtures can properly produce.

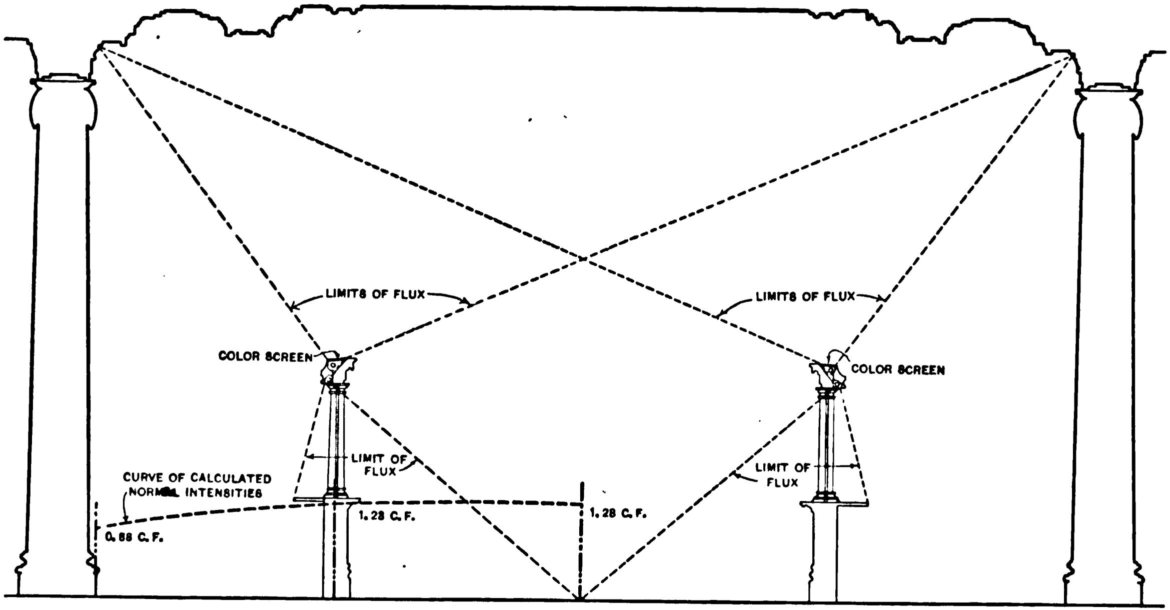


FIG. 4.—NORTH AND SOUTH SECTION THROUGH BANKING ROOM.

The design—a semi-indirect type with interior mirror reflectors and top of clear amber diffusing glass—is shown in Fig. 4. Each of the large fixtures contains a single 250-watt clear bulb tungsten lamp. The smaller fixtures of the same design on the mezzanine contain a 150-watt lamp. The energy of efficiency of these fixtures as light generators is comparatively low on account of the necessary equipment for color and diffusion. Their " effectiveness," is we believe one hundred per cent.

The net result of the use of these fixtures is perfect so far as the outer bays are concerned, but our gradation in the central space is still reversed. This we correct as follows: First by a gradation in color as we go up—from a whitish yellow through yellow to a warm orange like the light from a wood fire of glowing coals; second by low general intensities, and, third, by establishing a graded belt of more brilliant illumination in the public space. This last we can, fortunately accomplish by means of a trough reflector set in the bottom of the screen cornice as shown in Fig. 4. This device serves two purposes. First to throw light through the screen into the public space and second to furnish proper illumination on the screen counters as well as to light up the faces of the people outside the wickets. In addition to the light from this source there will also be some increase in the illumination of the lower planes in the room by light reflected from the working areas.

These, in brief, are the principal factors that determine the character of the equipment for general illumination so far as the design of the room is concerned. We now have to take up the illumination of the working areas themselves.

Our first consideration is that the scheme for general illumination can not be made adequate for working purposes. If the flux density were merely increased retaining its distribution not only would the architectural effect be weakened but the room would be uncomfortably brilliant. Besides a large amount of energy would be wasted.

The working areas constitute the surfaces of the various tables, desks and counters, and it is here and here only that any great flux density is needed. The total working area on the main floor is about 950 sq. ft. The total main floor area being approximately 7,650 sq. ft. it at once appears how wasteful it would be to light this entire area to a high intensity in order to produce the same intensity over one-eighth of it.

Let us assume that four foot-candles are required on the working area. Then 4 × 950 = 3,800 lumens is the working flux required. On the other hand, 4 × 7,650 = 30,600 lumens is the flux required when the working illumination is obtained from the general room illumination. We shall therefore go on the basis that each desk shall be provided with its own lighting devices.

Apart from the screen counters, the lighting of which has been described above, there are six types of desks and tables requiring in all five types of fixtures. These fixtures can be so designed that an even normal flux density of four foot-candles will be distributed over the working area and so directed that, with the eye in the normal position, there can be no direct reflection from papers on the desk. There is no essential difficulty in obtaining this result by the use of sectional mirror reflectors.

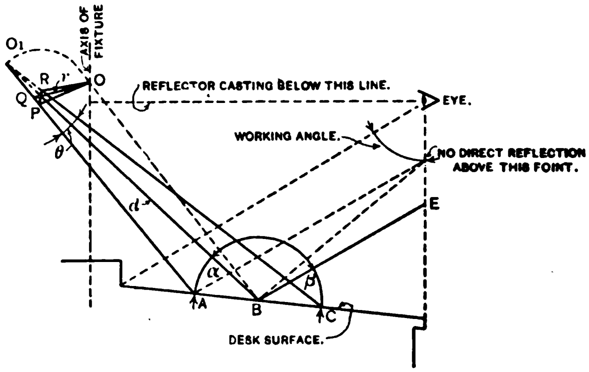

AXIS OF FIXTURE
O₁
R
r
O
Q
P
θ
d
REFLECTOR CASTING BELOW THIS LINE.
EYE.
WORKING ANGLE.
NO DIRECT REFLECTION ABOVE THIS POINT.
E
α
β
A
B
C
DESK SURFACE.

FIG. 5

The casings of these reflectors are of drawn bronze given a sand blasted oxidized finish to prevent the appearance of images by reflection. They also cut off all direct light from the eye.

The contour of the reflectors is designed geometrically for each type by working back from the illumination desired on the desk surface. The principle of the method may be expressed analytically as follows:

Divide the surface to be lighted, Fig. 5, into strips parallel with the light source. Let the width of each strip be such that the incident flux per unit length of each strip is the same. Let the width of one of these strips be $A\ C$. From a point E, safely below the normal eye position, draw lines such as $E\,B$ from E to the center of each strip. These are the limiting lines of direct reflection from the desk surface. Draw $B\,Q$ so that $\alpha = \beta$.

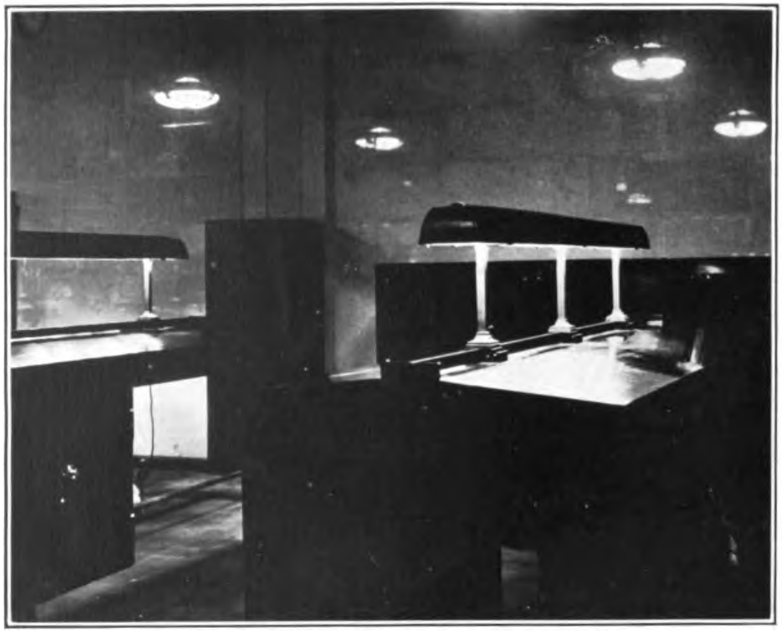
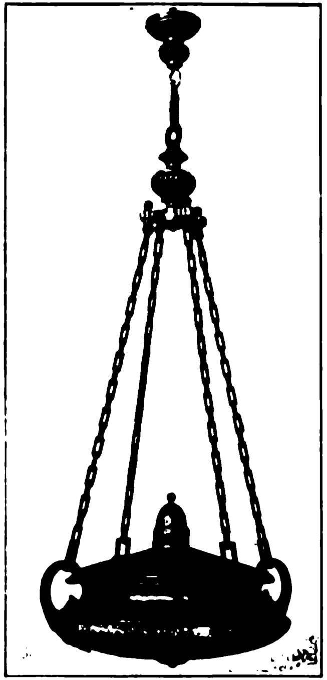


FIG. 6.—DESK LIGHTING. [JONES]



[JONES]

FIG. 9.—SEMI-INDIRECT FIXTURE.

These lines, $B\ Q$, are the limiting "flux lines" from the illuminant. Let any one of these lines intersect one strip $P\ R$ of the reflector at Q. Draw $A\ P$ and $C\ R$, and $P\ O$ and $R\ O$ so that the angles of incidents are equal to the angles of reflection. These lines meet at P, the center of the source assumed to be a luminous line, perpendicular to the plane of the paper. Let the angle $P\ O\ R = \theta$. The angle between $A\ P$ and $C\ R$ is also equal to θ. Let $Q\ O = r$, $Q\ B = d$, and let $r + d = s$.

If i is the intensity at B along d then the flux per unit length of source, and a strip, $A\ C$, enclosed within the angle θ is

$$\beta = \theta\, s\, i$$

Now if I be the source intensity in c.p. then

$$i = \frac{I}{s}\, C_1.$$

Where C_1 is the coefficient of reflection of the mirror. Then

$$\beta = \theta\, s \cdot \frac{I}{s}\, C_1 = \theta\, I\, c_1,$$

and

$$\theta = \frac{\beta}{I\, c_1};$$

from which, and the structural conditions the reflector contour may be plotted.

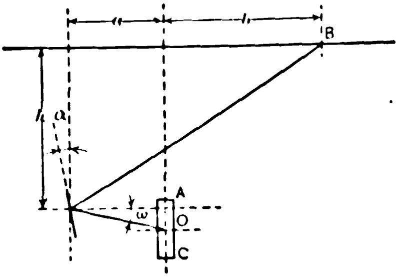


FIG. 7

A view of one desk lighted is shown in Fig. 6.

The calculations for the semi-indirect units and the indirect reflectors are based upon the same reasoning. It is important, however, to determine the angle at which the reflector in the semi-indirect unit be set.

In Fig. 7, let $A\ B$ be the lamp filament. Let $P\ R$ be a section of the reflector. Let b be the distance along the ceiling from the axis of the fixture to the point B at which it is desired to reinforce the flux density. It is required to find α, h being given.

Then

$$\alpha = \frac{1}{2}\left[\frac{\pi}{2} - \tan^{-1}\left(\frac{b + a}{h}\right) \mp \omega\right]$$

depending upon whether the center of the filament is above or below h. With α given of course h can be found.

Now let it be assumed, that on the central ceiling space of the room above discussed, we require an average apparent normal intensity of reflected light of one candle. The surface, being a reasonably good diffuser, the reflected flux per square foot is approximately 1.0π = 4.7 lumens.

The ceiling area being 1976 sq. ft., the total reflected flux is 1976 × 3.1 = 6125 lumens. Let us take 0.45 as the average absorption coefficient. The total flux absorbed is then 11136 − 6125 = 5011 lumens. Assuming 30 per cent average absorption in our color screens (seen in Fig. 1.) and loss in reflector we have as our net generated flux 8350 lumens. This can be generated by 44 25-watt lamps. Actually, and after trial, 36 were used.

The reflectors, however, were made considerably longer than the calculations indicated so that the necessary adjustment for shadows and color could be made. Finally about half ruby and half light amber screens were used, the ruby being central. It is perhaps, needless to say that the reflectors were so designed as to prevent any appearance of glare or sight of the lamps from the mezzanine floor.

A curve of normal intensities due to the illumination on the ceiling on a plane 30 in. above the floor is shown in Fig. 4. These intensities are calculated by the point by point method using a formula given by the writer in a paper " On Finite Line and Surface Light Sources."*

Let us now consider for a moment the method of obtaining the total generated flux required. This can be simply shown by the following table.

Surface	Area sq. ft.	Average incident flux density	Absorption coefficient	Diffusion coefficient	Required flux lumens
Central ceiling	1976	3.0	0.45	1.00	5011
Side bay ceilings	2900	2.0	0.40	1.25	2320
Soffits	184	2.0	0.40	1.25	147
Mez. ceiling	1875	2.0	0.50	1.00	1875
Upper half walls	5368	1.7	0.30	1.45	2689
Lower half walls	5368	1.7	0.30	1.45	2679
Upper half columns	1055	2.5	0.30	1.45	738
Lower half columns	1055	2.0	0.30	1.45	633
Floors	8333	2.0	0.75	1.25	2083

Total required flux...18175

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*Transactions I. E. S., Vol V, p. 298.

The calculations for the above are as follows. Let i be the required apparent normal intensity of reflected light per square foot of surface. If the surface shows perfect reflection as from a mirror then the intensity of the reflected beam in the direction of the angle of reflection equals the intensity of the incident beam in the direction of the angle of incidence. The received and reflected flux will, of course, be the same. So, if i_r is the intensity of the reflected beam, and i_i is the intensity of the incident beam, $i_r = i_i$. The normal intensity in this case is $i_r \cos \theta$ where θ is the angle between the normal and the direction of i_r. On the other hand, when the surface shows perfect diffusion, the maximum intensity of reflected light is along the normal. In any other direction it is $i \cos \theta$ where i is the normal intensity and θ the angle between the normal and the direction in which the intensity is measured. The polar or intensity curve of such a surface bounded by a circle is itself a circle whose diameter is the normal intensity and which is tangent to the surface at its center. The polar surface is therefore a sphere, and the reflected flux through a hemisphere bounded by the surface is πi lumens.

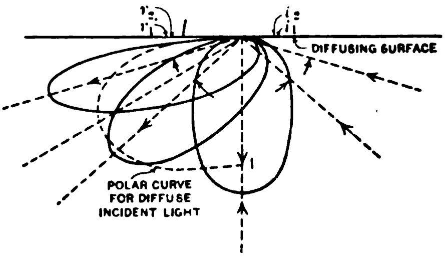

FIG. 8

We may have every variety of diffusion between these two extremes.

If then, as in Fig. 8, where $O\,A\,B$ is the polar curve of reflected intensities, we measure the normal intensity as i, πi will not give us the actual reflected flux, due to the high component of direct reflection. To obtain it we must multiply πi by some constant which we shall call the diffusion coefficient. For the same surface, this coefficient will be different for different arrangements of incident light. For a surface carefully painted with a non-lead priming body and a non-lead finish finely stippled we may take the diffusion coefficient to be 1.00 and practically independent of the arrangement of incident light.

Now let C_d be this coefficient. We may then write for β_r, the reflected flux

$$\beta_r = \pi\, i\, C_d.$$

If C_a be the absorption coefficient, that is, the fraction of the incident flux absorbed by the surface, then the incident flux must be given by

$$(1 - C_a)\, \beta_i = \pi\, i\, C_d.$$

In the case of any closed surface receiving a flux of energy from sources within the surface the only loss of energy is that absorbed by or transmitted through the surface. Hence to maintain a given quantity of energy within the surface the enclosed sources must constantly supply the losses.

We may then write for the total flux to be generated by the light sources in any given enclosure

$$\beta = \sum_s \beta_i\, C_a.$$

The total required flux given in the above table must be further increased by the losses in the fixtures and equipment to find the total flux generated at the lamps.

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(*Subject to final revision for the Transactions.*)

MEASURING STRAY CURRENTS IN UNDERGROUND PIPES

BY CARL HERING

The measurement of stray electric currents flowing through buried conductors, such as pipes, and generally originating from an electric railroad or other grounded system of electric distribution, is attended with various difficulties, particularly in the determination of the current which enters or leaves the underground pipe through the surrounding earth, and as it is the current which leaves a pipe in this way that corrodes it electrolytically it becomes important to be able to locate and measure that current. Another important measurement is to identify the original source of the stray current.

The purpose of the present paper is to describe several methods which the writer devised some years ago, for making these measurements, and which he used with success at that time in a practical case. The present description is published with the permission of the party for whom the measurements were made.

One of the problems given to the writer was to measure the currents in a pipe and to locate and measure the currents leaving it through the earth, by methods which were positive and not based on any questionable assumptions, and the results of which could be used as reliable evidence in court. Another was to identify the source of the stray currents flowing in pipes so as to establish the responsibility for them in legal proceedings. The methods therefore had to be unquestionably correct, and free from any questionable assumptions.

The usual method which consists in measuring the drop of potential in millivolts between two fixed points on one length of pipe exposed for that purpose, and then calculating the current from an assumed resistance of the pipe, would not answer the requirements, as the resistance of the pipe is a mere assumption which may be far wrong, even when based on measurements of other presumably similar pipes before they are laid. A little thought will show that such a test at best is only a crude one and the results would not be likely to stand the usual attacks in court proceedings. Even though many pipes may have been measured before laying and found to agree fairly well, there is always the uncertain factor of the wall thickness of that particular piece of pipe in service on which the drop of potential was taken. It is customary for instance in laying water pipes over a rolling country to use varying thicknesses as the pipe crosses a valley or a hill, and it is of course impossible for the one making the electric tests to measure this thickness himself. Drilling through or cutting the pipe was not permitted, as it was in service.

The method of using the academically interesting ground current detector, for measuring the current passing through a definite cross section of the ground near the pipe, was also excluded, as it involves disturbing the very conductor through which the current had been flowing, as also the assumption that the distribution of this current in the ground is uniform, which is not only not likely but highly improbable; in any case it is based on mere assumptions, and is therefore not positive and direct.

A magnetometer method was tried by suspending over the top of the exposed pipe an astatic couple having a long distance between the two needles; the lower needle was brought to a fixed distance from the outside of the pipe, hence within the field produced by the current in the pipe, while the other was far enough away to be practically outside of that field. The system will then tend to place itself perpendicular to the pipe, hence by bringing it parallel to the pipe by means of a torsion wire or a current in a neighboring coil, a measure of the external magnetic field and therefore of the internal current is obtained. This would be an extremely simple method, but it was found that the magnetic field around such a pipe was extremely irregular, the surface of the pipe showing numerous irregularly distributed poles; it was therefore also abandoned.

After trying out numerous other methods the following were found to be the best and were the ones actually used.

The fundamental principle is as follows. Let *P*, Fig. 1, be a part of an underground pipe which has been uncovered and through which an unkown current *I* is flowing as shown; at first let it be supposed that this current is steady, and of course a direct current. Let *D* be a sensitive galvanometer, millivoltmeter or any other form of detector of small differences of potential, connected as shown; there should preferably be no variable resistance like an unbonded pipe joint between the two contact points. Let *A* be an ammeter, *B* a few cells of accumulators and *R* an adjustable resistance; the shunt circuit containing them is connected as shown anywhere outside of the points of application of the voltage detector, the farther away the better—they may even be on the other side of a joint.

To find the current flowing in the pipe adjust the resistance *R* until *D* reads zero; then there will no longer be any current flowing in the shunted part of the pipe, hence the reading of the ammeter will give the current *I* in the pipe. The current may be said to have been sucked out of the pipe by the battery, and made to flow through the ammeter, where it can be measured; as far as the current in that short section is concerned the pipe circuit has in effect been electrically cut in two as though an insulating joint had been introduced.

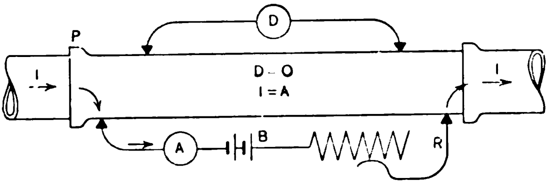

FIG. 1.

If *D* is a galvanometer with proportionate deflections, instead of a mere detector, then by taking a deflection immediately after the shunt circuit has been opened a reading proportionate to the drop of voltage for that current will be obtained. The instrument *D* is thereby calibrated to read the pipe currents directly and can be used for this purpose thereafter; the test with the battery current is therefore merely of the nature of a preliminary calibration, and need be carried out only once for each station.

If in addition this voltage instrument is calibrated to read directly in volts (usually in terms of milli- or microvolts as for instance a millivoltmeter,) then if the deflection reduced to millivolts is divided by the current it will give the resistance of the pipe in milliohms between the two points of application of the voltmeter, hence it enables the true resistance of the pipe to be measured. The distance between the two contact points is best made an exact number of feet, which standard length is then preferably kept the same for the whole series of tests on that line of pipes. From the resistance per foot obtained from tables a rough check of the measured result may be obtained.

In most cases it is advisable to make these connections for the voltmeter permanent and to bring wires from them to the surface before filling in the hole (being careful to mark one of them with a knot), for having once obtained the constant from this test with care, the current in the pipe can be measured any time thereafter, correctly and very simply with a mere millivoltmeter. The most convenient form of this constant is the amperes per millivolt, which is the conductance in millimhos.

The current which leaves or enters a pipe between any two points or stations can then be determined by making this calibration at each of the two stations and then taking simultaneous readings of the currents in the pipe at the two stations with two millivoltmeters or calibrated galvanometers; the difference between these currents will then show the amount of this current, and whether it is leaving or entering.

This becomes possible by this method because it is a positive one, involving no questionable assumption, and because the measurements can be made with all necessary accuracy, if one has sufficiently sensitive and reliable instruments; it can, therefore be depended upon to measure the current with sufficient accuracy at two neighboring stations so that the difference between the readings gives a reliable measurement of the entering or leaving current. If the pipe current measurements were dependent, as they often are by the older method, on an assumed pipe resistance, such a measurement based on taking the difference between two currents would not be permissible, as the probable error would be so great that the results might even make it appear that the current was entering when it was in fact leaving the pipe.

In this method shown in Fig. 1 there should be no current leaving or entering the pipe between the points of application of the shunt, hence the hole should be free from water and there should be no moist earth in contact with that part of the pipe.

It is assumed in this method that the short length of pipe between the shunt contacts is too small a fraction of the whole circuit of the pipe line currents to alter these currents when that section is practically cut out of circuit, as it is when the current flows through the shunt. This assumption is probably absolutely safe in all cases in practise.

As this method is not in any way concerned with the nature of the circuit beyond the single pipe length under test, nor with the rest of the path of the current, it can be applied to the most complex network of pipes, even when the pipes are interconnected together elsewhere or bonded to the track.

In measuring the pipe resistance by this method, or in general when the voltage drop is measured, it is of course assumed that the current is constant while the two successive readings are taken, hence it is recommended to repeat the two readings a number of times. When this constancy of current cannot be assumed, one of the modifications of this method described below may be used.

A portable millivoltmeter with a full scale deflection of 10 millivolts has divisions of 0.1 millivolt, hence can be estimated to 0.01 millivolt. If a 16-in. (40.6-cm.) cast iron pipe has a resistance of about 0.00001 ohm per foot (30.5 cm.), then say 5 feet (1.5 m.) will give a drop of half a division per ampere. This will give a rough idea of the range of measurements that can be made with a millivoltmeter. Improvements may perhaps also be made in these instruments to make them still more sensitive.

When a portable galvanometer is used instead of a millivoltmeter in order to get greater sensitiveness, like the mirror and telescope galvanometers that were used in these tests by the writer, it is necessary to calibrate it for volts while in place before each test, hence a convenient way of doing so should be provided. With the accumulator, ammeter and rheostat available in this test, this is easily done by passing a known current through a known low resistance, giving a known drop which is then used to calibrate the instrument. Such a galvanometer should be provided with the usual shunts, and if so it can also be calibrated with a millivoltmeter which is always at hand for such tests.

When such galvanometers are made extremely sensitive, as would be desired for instance when the pipes are very large and thick or the current very small, they are apt to have a loose zero or give somewhat indefinite deflections. Attention is therefore called to the fact that small deflections, when they are very definite and when the instrument has a rigid zero, as in a good portable millivoltmeter, may be more accurate and reliable than larger deflections in a galvanometer that is more sensitive but has a loose and unreliable zero and less definite or not strictly proportional deflections. Instead of using exceedingly sensitive instruments it may be better to use greater lengths of the pipe, even to the extent of including a joint, which in that case should preferably be bonded so that it is not variable.

In practise there are various very desirable modifications of the method which is shown only in its simplest form in Fig. 1.

Instead of attempting to adjust the current in the shunt to bring the voltage *D* to zero, it is far more convenient to use a regular measuring instrument for *D* instead of a mere zero detector, and then to pass a definite current through the shunt, say 10, 50 or 100 amperes, and read the two deflections of *D* when this current is on and off; this had best be repeated several times. The difference between these two readings then corresponds to that current, from which data the instrument can be calibrated to read in amperes. The best current to use is that which will reduce the original deflection as much as possible. By thus using the difference between a large and a small deflection the errors due to a loose zero, which are so common with highly sensitive instruments, are reduced.

This method also has the advantage that an observer can read both *A* and *D*, as he first adjusts the rheostat to give the exact predetermined current and after that can open and close the switch to throw this current on or off, without having to read the ammeter, this current being absolutely constant. He need, therefore, read only *D*.

All the above applies to steady currents or to such as are steady long enough (a few seconds) to take two successive readings, as the voltage drop and the current cannot be measured simultaneously in the form shown in Fig. 1. In practise such stray currents are likely to vary continuously and often very rapidly. By waiting for a suitable opportunity when the current is practically constant for a short time, measurements of sufficient accuracy can often be made, and as this part of the test is only for the calibration, hence of a preliminary nature and needing to be made only once for each station, one is justified in taking more time for it. It may be facilitated by using an extra voltage detector applied somewhere outside of the shunted part (as in Fig. 3) and having an additional observer to call out when it is steady or to note whether or not it had been steady while the other pair of readings was taken.

When, however, the fluctuations are too rapid, the following modification can be used; it proved to be very satisfactory in practise, although somewhat more cumbersome, and requiring additional apparatus, though no more observers.

Let the left hand side of Fig. 2 represent the same arrangement as in Fig. 1. A second voltage detector *D* is then added as shown; it may be a sensitive galvanometer and need not be calibrated. *S* is a second shunt circuit containing a battery and an adjustable resistance which is operated by the observer of *D*, who keeps adjusting it continuously so as to maintain the deflection in *D* constant. During that time the current will be steady for the other observer, who then completes a set of readings with the other instrument *V* according to the method shown in Fig. 1.

The purpose of the additional shunt *S* is to take up all the excess of the pipe current above a certain amount, thus acting as a sort of overflow, taking care of the peaks only. The observer of *D* must, therefore, use some judgment in selecting the deflection at which the current is to be held constant; it should be kept at about the base of the average peaks, but should not be too low for the other observer to get good readings for his calibration. It may be a different deflection for each set of readings of the other observer; the only important point is that the current should be held constant in that length of pipe for a long enough time to take two successive readings, requiring only a few seconds.

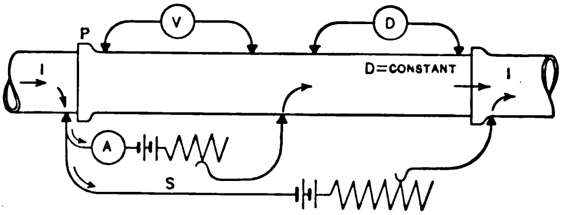

FIG. 2.

Or, if practicable, the observer of *D* could shunt off the whole pipe current, thus making *D* read zero, and leaving the pipe entirely free from current for the other observer to make his calibration or any other test for which it is required to have the the pipe free from current.

The adjustable resistance for this extra shunt *S* should be made of a pile of carbon plates which are compressed by means of a lever so that the observer of *D* may quickly follow the variations of the current with it. Very good results were obtained with such an arrangement after a little practise. As the observer of *D* knows whether or not the current has been successfully kept constant he can discard the readings of the other observer for which the current had not been constant. By taking the mean of a number of good readings, very satisfactory results were obtained.

Having thus calibrated the voltmeter *V* at each of two neighboring stations, the currents which enter or leave the pipe between them may be determined, with the fluctuating currents, by taking the readings of the two instruments simultaneously by means of visual or telephonic signals, preferably at times when the currents are momentarily steady.

It may be of interest to state here that after making the calibrations in this way over miles of the same line of pipe, at numerous stations, to determine the places where the current enters or leaves, and its amount, and also to measure the current in the pipe itself, the results were finally all reduced to the resistances in milliohms per foot of pipe, in order to see how they agreed, as the pipe had nominally the same outside diameter throughout the entire length. They were found, however, to differ very greatly, far too much to be due to errors of measurement. The writer, therefore, concluded that the pipes in different parts of the line must have different thicknesses, and upon examining the specifications according to which the pipe line was laid, this was found to be true, thicker pipes having been used in the valleys and thinner ones over the hills. Upon making comparisons with the specified thicknesses the results agreed very well with the measured resistances, showing the reliability of the method of measurement.

Incidentally this also showed the serious errors which might arise by using the older method based on the assumed resistance of the pipe, it being often impossible to state after the pipe had been laid and was in service, what thickness the particular piece under test had. In the present case those who made the electrical tests of this pipe line had not been informed that the pipe varied greatly in thickness.

Another modification of the method for use when the currents are very unsteady is shown in Fig. 3. The apparatus is similar to that in Fig. 2, except that the additional shunt with its battery and rheostat is not required, but on the other hand three observers are required instead of two. The positions of *D* and *V* are now reversed, the important instrument *V*, to be calibrated, being now placed beyond the shunt, while *D*, which may be a mere detector or galvanometer, is connected to the points within the shunted part. The resistances *R* and *R* need not now be equal as marked on the diagram.

The shunt current is first adjusted to some convenient average value of that flowing in the pipe, then as the latter fluctuates on both sides of this value there will be times when it is exactly equal to it; this is indicated by *D* reading zero, and at that moment the observers of *A* and *V* take their readings. This can be repeated for different currents. The quotient of *A* divided by *V* should then be a constant for all the readings; this calibrates the instrument *V* as it gives the amperes per division, and it can therefore be used as a pipe current ammeter thereafter.

This method was not tried. It requires a battery, leads and connections large enough for the whole pipe current, and a constant flow of the current for a long enough time to get a number of good readings; this may sometimes require rather large battery and leads. But if the observer of *D* manipulates a carbon plate rheostat rapidly to keep his instrument at zero, it ought not to take long to get a group of good readings.

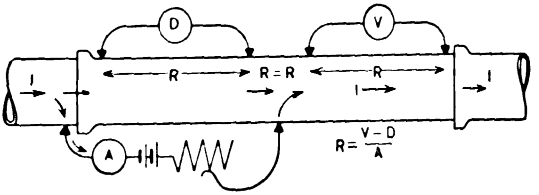

FIG. 3.

If in this method shown in Fig. 3, the instrument *D* is also a measuring instrument instead of a mere zero detector, then the following modifications can be used. The two instruments *D* and *V* need not then be calibrated in volts, hence they can be two uncalibrated galvanometers, provided only that they are exactly alike in giving the same deflections when connected in multiple; they may be adjusted to do so by a series resistance. Two good millivoltmeters would do in cases in which the deflections are large enough and accurate enough so that their *difference* may be relied upon as being an accurately measured quantity, for the present modification of the method is based on measuring this difference.

Having two such instruments, adjust the points of contact for either *D* or *V* so that the two instruments always read alike for the pipe current alone, however fluctuating that current may be. This, of course, must not be done by an adjustable resistance in the circuit of the instrument, but by moving the contacts on the pipe, hence this method cannot be used directly when all four of these contacts are drilled or soldered, although it may then be used indirectly, as shown later. Three of them may be permanent and the adjustment made with the fourth.

Such connections mean that the two pipe resistances shunting these instruments are equal, as any current then gives the same drop in both. If now any known part of the current be sucked out of the pipe by the battery shunt as before, then, as the two resistances are equal, the difference between the readings *D* and *V* must correspond with the difference between the two currents in these two parts of the pipe, and this difference between the currents is of course equal to the known battery curent *A*. Hence dividing this known battery current by the difference between the two deflections calibrates both of the instruments for reading pipe currents thereafter, that is either of them will then give the amperes per unit deflection. It is precisely like the method described above, except that the two readings which then were necessarily successive are now simultaneous.

It will be noticed that as only the difference between the two currents is now involved, and as this difference is always constant, the method does not assume even a momentary constancy of the pipe current, being entirely independent of it; this current in the pipe may therefore fluctuate over wide ranges, the only important point being that with such fluctuating currents the two readings must be taken simultaneously. And as the calibration depends on the difference between two readings, the larger one should be as large as possible and the smaller one as small as possible, hence the battery current should be made as nearly equal to the pipe current as practicable.

As the battery current in the shunt is in practise governed entirely by the adjustable resistance in that shunt circuit, this local current will remain constant no matter how much the pipe current varies. Hence it can be adjusted and noted prior to the taking of the two simultaneous readings, thus saving one observer. Moreover, this shunt current can be adjusted to any convenient number of amperes, 10, 20, 50, etc., so as to simplify subsequent calculations.

As before, the above measurements will also enable one to calculate the resistance of those parts of the pipe which are embraced by these two instruments, provided the latter are calibrated to read in volts, and are not merely deflection instruments. The readings in millivolts, divided by the now known currents in amperes then give the pipe resistances in milliohms.

If it is not convenient to adjust the contacts on the pipe so that the readings of the two instruments are alike, the inequality of these readings may be allowed for by calculation. For simplifying the rough mental calculations which a careful testing engineer should always make during a test to see that there are no grave errors, wrong connections or inconsistencies, it is advisable to make the two distances between the pairs of contacts approximately equal so that the ratios between the deflections will be approximately unity.

A preliminary test is then made to determine this correction factor accurately. This is done by taking a series of simultaneous readings on the pipe current only, or if too small, then supplemented by the battery current which should then be reversed, so as to add to instead of deducting from the pipe current, and it must of course now flow through the both pieces of pipe, and not as shown in the figure.

From this preliminary series of readings a good average value can be obtained for the ratio of the readings of D divided by the corresponding ones of V. Call this n. Then all subsequent readings of the instrument V in the main test must be multiplied by this correction factor n, to reduce them to what they would be if the two pipe resistances had been equal as at first described.

In general the modifications shown in Figs. 2 and 3 have the disadvantage, as compared with that in Fig. 1, that they require an exposure of a larger part of the pipe; the alternative of using shorter lengths for each instrument is not recommended—these lengths should be as great as conditions permit, preferably each a whole pipe length.

In the writer's tests the galvanometers had been designed for different conditions and were therefore somewhat oversensitive; the zero was too loose and the deflections were not as definite and accurate as desired to give the best results which these methods could give. The deflections of millivoltmeters under the existing conditions were considered to be too small and therefore too unreliable for methods depending on calculations involving the relations of quotients and differences. The galvanometers should have had stiffer suspensions, giving them more rigid zeros and more definite deflections, at a sacrifice of some of their sensitiveness.

The present modification of the method was tried out with millivoltmeters in a single one of the tests of the above mentioned series where the pipe current was greatest, and although, the deflections were small, the calculated results seemed to be concordant, although there was no way of checking them with results from other observations or with repetitions under different conditions. In the laboratory this latter method may be a very satisfactory one, but whether it will be so on a series of outdoor road tests should be determined by the testing engineer when he knows the particular conditions of the test and the characteristics and reliability of his instruments. It has several very good features and might in some cases give very good results.

Attention is here called to the great importance of having the directions of the currents correct in all these tests.

In general, methods which give the final results as directly as possible and in intelligible form, are to be preferred to those of the indirect kind in which the readings themselves convey no meaning and in which the final results must be calculated from more or less involved mathematical relations, which it may not be convenient to work out during the test itself to see whether there are any grave errors, wrong connections, or inconsistencies. This is particularly true of road tests in which the apparatus is moved rapidly from station to station and in which holes are dug which must be filled in again as soon as possible; in such tests it would be awkward to find later, when the calculations have been made in the office, that there had been something wrong, requiring a repetition of an expensive test.

Another objection to the indirect kind of tests, in which the final results are calculated from formulas, is that such formulas may involve quotients, differences and relations between them, and in such cases it may be the case that small inaccuracies in the readings mean very large ones in the final results, as for instance in taking the difference between two small and nearly equal readings. And such inaccuracies may not be included in the academician's calculated " probable error," as they may lie back of the readings. A rigid zero, definite and strictly proportionate deflections, accurate and strictly simultaneous readings, etc., may be necessary for such calculated results. The indirect methods may be quite correct in theory and may give very good results in laboratories where one may work out the best possible conditions, instead of having to take them as one finds them, as in road tests.

The other test referred to in the introduction concerns the identification of the source of the stray currents in the pipes. This is often important in legal proceedings, for even if currents are shown to be flowing in pipes the question of where they come from still remains.

The method devised by the writer, and used very successfully in a large number of tests, consists in taking a series of many simultaneous readings of the drop of potential or the current, in the pipe and in the track of the supposed source, especially the extreme high and low readings of the fluctuations, and plotting them together on the same sheet of cross section paper, using different scales if necessary to make the average ordinates nearly equal. If the prominent peaks and troughs of these two saw-tooth curves then correspond approximately with each other, there is no doubt that both the currents originate from the same source. If the curves are radically different then that track is either not the right source or at least is not the only one.

In the tests referred to, these identification measurements were made over long stretches of several miles, with the aid of telegraph wires, but it is possible that good results could also be obtained in certain cases with millivoltmeters applied to stretches short enough not to require the use of long telegraph wires. The readings need not be in volts or amperes. They merely need to be proportional to them; hence the instruments need not be accurately calibrated, but should give correct proportional deflections. Nor need the resistance of the telegraph wire leads be taken into account.

Numerous other tests concerning such stray currents were devised by the writer which may be new, but those described above were considered to be the best. There were also a number of other tests proposed and in part used in this series, but as they were devised in conjunction with others the writer does not feel at liberty to describe them here.

As the above described methods for measuring the pipe currents and resistances are entirely independent of the rest of the pipe circuit or the rest of the path of the current, they may also be applied to other tests than those of underground pipes, in which the rest of the circuit is also unknown or inaccessible, as for instance in measuring the resistance of a part of a circuit such as a bus bar, a permanently connected shunt, etc., through which current is flowing and which is in service and can therefore not be cut or have its current interfered with. Or the current may be alternating. There are of course numerous other modifications of the same general principle, which may be made in special cases.

The apparatus used for the pipe current tests consisted of two portable, low resistance, suspension coil, mirror and telescope galvanometers on tripods, of the type used for outdoor insulation tests, with the usual set of shunts, but made very sensitive, as the original requirements were to include measurements of even relatively very small currents in rather large pipes. Their constants were about 0.001 millivolt per mm. For ordinary work they would not need to be so sensitive. Probably in many cases two sensitive but reliable millivoltmeters would be sufficient to carry out the above mentioned tests; if so, they are of course decidedly preferable on account of their portability, especially when high speed automobiles are incessantly passing along the road uncomfortably close to the instrument and observer.

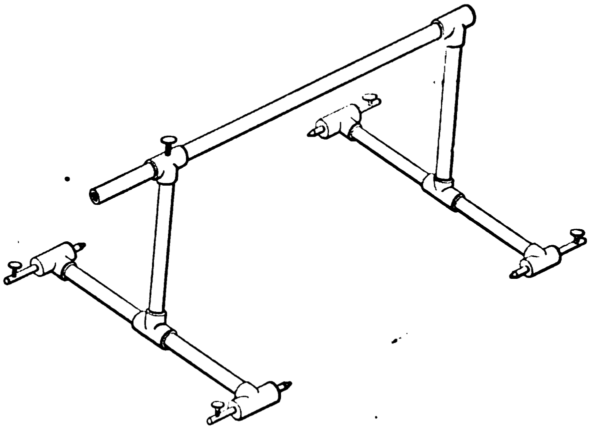

FIG. 4

The rest of the apparatus consisted of a wire rheostat, a reversing switch, a small portable two-cell accumulator capable of giving about 100 amperes, and a millivoltmeter with several shunts to be used as an ammeter also, all conveniently mounted in a portable box serviceable also as a writing table. A single cell would probably have answered nearly as well. For the preferred form of test shown in Fig. 2 there was in addition a carbon plate resistance with a lever for quick and strong compression, a second set of two cells of accumulators and a sensitive millivoltmeter.

The form of the universal clamps finally adopted for making the contacts with the pipes is shown in outline in Fig. 4; these clamps proved to be very convenient. They spanned the pipe, making contacts for the same lead at two diametrically opposite points. The contact pins were made with hardened points which with a light hammer blow entered the pipe slightly and made serviceable contacts even for currents of 100 amperes. These pins were insulated from the frame so that they could be used for different circuits if desired. The clamps were made of light bicycle tubing and ordinary T-joints.

A paper to be presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

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(*Subject to final revision for the Transactions.*)

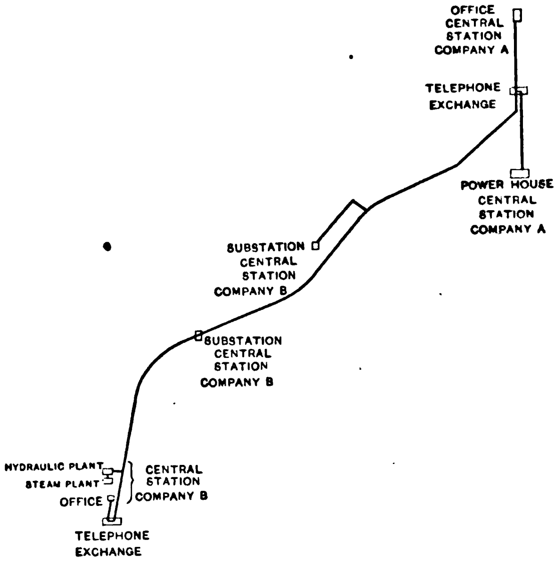
ELECTRICAL TRANSMISSION OF ELECTRICAL MEASUREMENTS

BY O. J. BLISS

The unique arrangement of standard instruments described in this paper was made for the purpose of transmitting and reproducing at a distance a direct electrical measurement, the distance in point being 35 miles (56 km.), the measurement the indicated kilowatts input to a 12,000-volt, 60-cycle, three-phase transmission line, and the medium of transmission a telephone line owned by the local telephone company but used as a private line by the central station companies.

The conditions which led to the necessity for the arrangement were these: First, a contract for power to be furnished by a large central station company which we will call *A*, to a smaller central station company called *B*, over a 35-mile (56 km.) three-phase transmission line, the smaller company being a customer of the larger and having substations of its own tapped off the connecting line. Second, a form of contract requiring that billing be done from the readings of a polyphase watt-hour meter installed in central station *A*, equipped with a printing device adjusted to automatically print the dial readings on a paper ribbon at intervals of 15 minutes, the charges to include a certain rate per kilowatt-hour for all energy delivered, a kilowatt-year charge based on the average of the three highest one-half hour peaks occurring during the year and a guarantee of a certain load factor.

With a contract of this kind it is evidently very much to the advantage of the customer to keep the load curve free from any peaks which would increase the kilowatt-year charge. But as the customer can only regulate at his own station and in the case in question the operators at *B* had no means of knowing what the input to the line was by central station company *A*, it became apparent that instruments must be installed in the stations of the smaller company which would indicate this input. Considerable advantage would also result if some permanent record could be obtained in order to check the watchfulness of switchboard operators, and as a comparison with the printed registration of the polyphase watthour meter in station *A*. It was desirable therefore to install a curve-drawing as well as an indicating instrument.


OFFICE CENTRAL STATION COMPANY A
TELEPHONE EXCHANGE
POWER HOUSE CENTRAL STATION COMPANY A
SUBSTATION CENTRAL STATION COMPANY B
SUBSTATION CENTRAL STATION COMPANY B
HYDRAULIC PLANT
STEAM PLANT
OFFICE
CENTRAL STATION COMPANY B
TELEPHONE EXCHANGE

MAP SHOWING LOCATION OF TELEPHONE STATIONS.

In developing a scheme permission was first obtained from the telephone company to use the private line for the transmission of signals between the stations, it being understood that any arrangement installed for that purpose should in no way interfere with the telephone service nor should an e.m.f. of over 50 volts be put on the line.

Standard types of meters were then modified and installed as follows. On the switchboard of central station *A* was mounted a graphic recording wattmeter, with relay type of movement, connected through the regular equipment of current and potential transformers to the transmission line. Alongside the wattmeter a small special variable rheostat was installed, the movable contact of which was connected, by a brass rod provided with an insulating joint, to the recording mechanism of the graphic meter so that the position of this contact at all times corresponded exactly to the deflection of the meter.

If now a direct-current source is connected across the rheostat terminals, and one terminal and the movable contact connected to the telephone line, the e.m.f. across the line has a fixed relation to the deflection of the graphic meter, or the input to the transmission line, and the reading of a direct-current instrument connected in the telephone line may therefore be made to indicate this input.

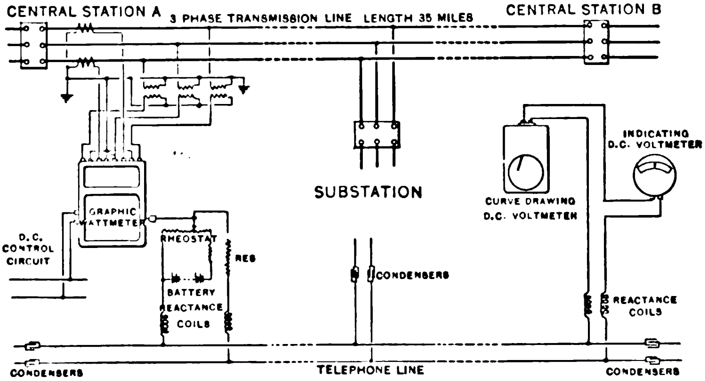


Diagram of Connections for Transmission of Electrical Measurements over Telephone Line.

The rheostat as made up has uniform resistance per unit of length and does not therefore give uniform increments of e.m.f. for equal distances of travel of the movable contact. By making the current through the resistance large as compared to the instrument current the error is, however, negligible, and the e.m.f. is considered directly proportional to the deflection of the graphic meter.

The source of direct current is a 36-volt storage battery of small capacity located near the switchboard. The continuous discharge rate through the rheostat is about 150 milli-amperes. The direct-current instruments, one an indicating voltmeter installed in the steam plant of central station company *B*, the other a curve-drawing voltmeter with smoke chart recorder installed in the water power plant of central station company *B*, are in series, are adjusted to the same full scale current, about 7 milliamperes, have scales marked in kilowatts and have series resistances adjusted to give full scale deflection corresponding to the graphic meter in central station *A*.

One-half of this resistance is in one of the meters in central station *B*, and one-half is mounted on the rheostat in central station *A*. This is necessary because the signalling system forms at both ends of the telephone line a shunt across the line, which must be of at least 1,000 ohms resistance in order not to interfere with the telephone service.

Interference with the telephone by the direct current of the transmitting system is prevented by the installation of condensers in the line at each telephone station, and interference with the meters by the telephone ringing current is prevented by the installation of reactance coils in the instrument leads.

The operation of this system has been so satisfactory, is so simple in its various parts, and has given such a small amount of trouble, that it leads one to believe the scheme practicable for many other applications. For instance, any two stations, whether belonging to the same company or not, if feeding into the same load, might use a system of this kind to advantage. A central office could have a continuous record of total output or that of any more important line or machine. Regulation of machines for synchronizing operations where the switch to be closed is in a station remote from that in which generators are located, as is sometimes the case in interconnected systems, could be easily arranged, or the more important positions on the load dispatcher's board might be made automatic, showing switching operations without waiting for the telephone call and the subsequent plugging or marking of the board.

In short, the installation here described seems to show that any points connected by telephone lines may be equipped for the transmission of measurements or direct-current signals at a low cost, without interference with the telephone system.

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METERING LARGE DIRECT-CURRENT INSTALLATIONS

BY F. V. MAGALHAES

The question of properly metering electrical energy when it is used in the form of high values of direct current is one that can profitably be discussed at this meeting. The following brief paper is intended as a summary, for the purpose of discussion, of various methods now being used, with suggestions for the development of apparatus that would eliminate certain disadvantages and errors now encountered.

We will consider the methods of metering currents of 1,000 to 10,000 amperes at 100 to 600 volts. These limits are arbitrary but they cover a great many conditions which are comparable in metering both the energy for light and power from central stations and the energy from electric railway substations.

Below is given a list of four headings which will in turn be dealt with in detail.

Method. 1. Install a single watt-hour meter between the source of supply and the distributing switchboard.

Method 2. Install in parallel in the main source of supply several watt-hour meters with an aggregate capacity sufficient for the total load.

Method 3. Divide the main service supply and meter separately any natural component parts of the total load.

Method 4. The development and the use of the shunt type of watt-hour meter both for the metering itself and for test purposes in connection with any of the three foregoing methods.

METHOD 1

The practise of installing only a single watt-hour meter is the easiest, best appearing and cheapest from the standpoint of switchboard design, and the cheapest from the standpoint of initial meter cost. The method, however, has the least to recommend it from the standpoint of meter accuracy, and is the most difficult and expensive to maintain after installation.

The advantages that may be claimed for this method are the registration on one set of dials of the total energy for the installation; also, as indicated above, the low initial meter cost as compared with other methods. This latter condition, however, is open to argument if careful consideration is given to the fact that a system of using several small meters permits more flexibility from the standpoint of exact assignment, as the rated ampere capacities of large meters are, from the manufacturing standpoint, necessarily arbitrary and in large steps.

The disadvantages that may be listed are: the possibility of complete interruption of registration or inaccurate registration due to a defect or to poor performance of the meter, such interruption or inaccuracy of registration applying over the energy for the total installation; extreme difficulty of proper testing, involving the insertion of instruments in the main circuit, the possible shunting of the customer's load and handling of an artificial load; the expense of owning and calibrating standards of very high current capacity; and the loss of registration due to the shunted load during the time of test.

METHOD 2

The practise of installing several meters in parallel, while increasing somewhat the initial meter cost and possibly the switchboard cost, tends to eliminate or improve several of the disadvantages of Method 1.

In case of defect or inaccuracy in a meter only part of the total registration is affected.

Testing is greatly simplified over Method 1, as the meters may in turn be disconnected on the house side for test and the remaining meters allowed to carry the load. The test connections, artificial load and capacity of the standard instruments will all be of smaller ampere capacity than in Method 1, with a corresponding decrease in initial cost and cost of maintenance.

This method is subject to one disadvantage in common with Method 1, namely, the poor performance of the aggregate meters at very light loads. A light load may exist for several hours which would be of considerable significance from the standpoint of energy, but which might be inaccurately metered, as it would be only a small percentage of the total meter capacity.

One disadvantage peculiar to this method is that the separate meters, due to differences in the resistance of the connections, may not register their proportionate part of the total energy. Such difference in registration even when the meters are entirely accurate, can give rise to unnecessary question or criticism of meter accuracy.

METHOD 3

The practise of installing individual meters for the natural component parts of an installation, such as separate floors in a building, separate buildings in a group, separate motors in a large power installation or separate rotaries in a substation, is, if the meter sizes are carefully assigned and the meters properly maintained, the best method for most conditions.

This method is open to the same objections that may be advanced against Method 2 as to the increased installation and meter cost.

Method 3 has a distinct advantage over the first two methods in that the assignment of each meter may be made very closely by considering the performance of its particular installation. The aggregate light load and overload performance of the individual meters will then be better than the performance of a single large meter or group of parallel meters on the total load.

The development of a mechanical or electrical totalizing dial of some description would, in connection with Methods 2 and 3, provide a single totalized record of registration of the various meters. Such a record might be desirable or even essential in the case of a rotary substation, with the individual rotary meters installed near the rotaries and a totalizing dial located on the switchboard.

METHOD 4

Method 4 is a proposed practise based on the development of an accurate shunt type of watt-hour meter.

Assuming the availability of such a shunt type of watt-hour meter for service purposes and a carefully designed shunt type of portable watt-hour meter for test purposes, the metering of large direct-current installations would at once present other possibilities. It would be possible to meter a large power installation, consisting of a few units, with a single meter. This meter could at frequent intervals be compared quickly and accurately with the rotating standard. The service meter and the standard being of similar types and characteristics would permit the use, for test purposes, of the regular service load, even if of a very fluctuating character.

One marked advantage of the shunt type of meter in the large capacities would be its flexibility from the stock standpoint. The meters themselves could be all of five or ten amperes capacity and the range for the large capacities maintained by a stock of shunts. This feature is comparable with the flexibility which is possible with the standard five-ampere induction meter in connection with any ratio of current transformer.

For an installation of small power units or a large lighting installation, Method 3, namely, metering separate parts of the installation, would still be desirable even with the availability of the shunt type of meter. Such a type of meter would, however, increase the ease of testing and thus indirectly increase the accuracy of registration.

In conclusion it can be stated that the requirement of a brief paper has necessarily resulted in the discussion of only one narrow phase of the general subject of metering. The possibilities of the shunt type of meter have by no means been completely covered. No mention has been made of the proper assignment of the present type of astatic and four-pole meters for different installations and switchboard designs. Nor has the subject of proper instruments and artificial loads for test purposes been dealt with, although all of these points are related and essential to the proper metering of large direct-current installations.

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A TUBULAR ELECTRODYNAMOMETER FOR HEAVY CURRENTS

BY P. G. AGNEW

THEORY OF INSTRUMENT

To obtain the same current distribution for both alternating and direct current it is usual to strand the windings of the field coils of electrodynamometers, and the strands should also be thoroughly mixed so that all shall have the same effective resistance and inductance. For very heavy currents this becomes a matter of extreme difficulty.

In the present instrument an entirely different means of obtaining the same end is employed. Evidently the ultimate requisite in an instrument for transferring from alternating to direct current is that the torque shall be the same, and it is immaterial whether we make the current distribution the same, or the field due to the current the same. The latter is the method adopted. There is no theoretical reason why the current distribution and the magnetic field could not both be allowed to vary if it could be shown that the torque did not change.

The field " coil " of the instrument consists of two coaxial copper tubes, thus giving a circular magnetic field in the space between the tubes. On direct current the distribution may be assumed to be uniform over the cross section of the tubes, but on alternating current, as is well known, the stream lines are crowded toward the outside of the inside tube and toward the inside of the outside tube, and the amount of this change depends upon the frequency. But it may easily be shown that if we have axial symmetry the magnetic field at any point is independent of the current distribution. Expressed in the usual terms there is no magnetic field between the tubes due to the outside tube, and that due to the inside tube is independent of the skin effect, but it is better to consider the arrangement as a special case of a more general principle.

Let us consider a generalized toroid such as would be formed by rotating any closed circuit such as A (Fig. 1) about an axis. We may think of the circuit A as consisting of a wire carrying a current, and similarly of the surface of revolution as being a current sheet. Or we may think of the surface as being wound with a layer of wire with no space between turns and thus becoming an endless solenoid.

It has been shown by Maxwell[1] and by Gray[2] that the field at any point, as at O, is independent of the size, shape and thickness of the conductor and depends only on the total current and the distance of the point from the axis. This may be shown by a very simple process of reasoning. The all-important condition is axial symmetry.

Consider a circle perpendicular to the plane of the paper, and cutting it in the points O and O'. This circle links once with the current. Hence the line integral of the magnetic field around this circle, or the work required to carry a unit pole around it, is 4π times the total current, or, if we remember that H is uniform around the circle,

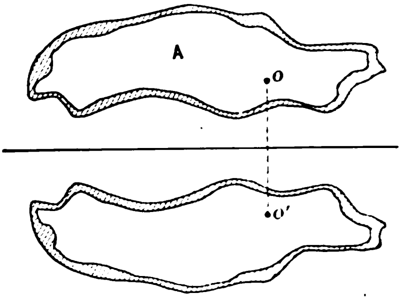

FIG. 1.—THE GENERALIZED TOROID.

$$2\pi R H = 4\pi I$$
$$H = 2I/R$$

The value of H at any point within is thus entirely independent of the dimensions of the conductor, provided there is axial symmetry. Hence an approximation to such a form for the current coils is admirably adapted for alternating-direct-current transfer dynamometers, since it is independent of the current distribution.[3]

It will be seen that the concentric tubes form an approximation to a toroid or an endless solenoid of one turn. It can only be an approximation since it must be open at one end in order to introduce the current.

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[1] "Electricity and Magnetism," Vol. II, Art. 681.

[2] "Absolute Measurements," Vol. II, page 278.

[3] For a detailed discussion of this principle and its application to electrodynamometers, see Agnew and Fitch, *Elec. Rev.* (Chicago), 60, p. 767, 1912.

CONSTRUCTION

Fig. 2, which is a vertical longitudinal section through the instrument, shows the general arrangement. The tubes are horizontal in order to allow a vertical suspension, and the moving coils are placed astatically, one above and one below the inner tube. These are shown in the plane of the section instead of in the mean working position, which is nearly perpendicular to the plane of the paper. This is done in order to show the shape of the coils, which are wound on ivory frames. They are held together by fine silver wires, one on either side of the inner tube, as indicated in the figure.

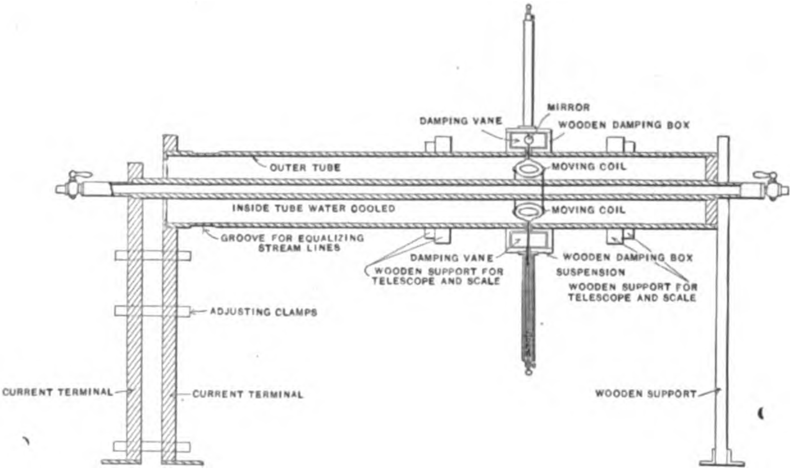

FIG. 2.—TUBULAR DYNAMOMETER.

Phosphor bronze strip suspensions are used, and two air damping vanes are provided. The damping boxes are of wood and are mounted directly on the outside copper tube. The instrument is read by telescope and scale.

Massive copper slabs placed parallel and 4 cm. apart serve as current terminals. They are provided with 5 bolts so arranged that any number of parallel leads up to 5 may be connected symmetrically. These at the same time serve as supports for one end of the instrument, and the closed end is supported by an oak upright.

Water cooling is provided for the inside tube by passing water through it, but no special means are provided for cooling the outside tube.

While the very heavy copper slabs used for current terminals tend to equalize the stream lines in the larger tube about the axis as a line of symmetry, this was deemed insufficient for the most precise work. Accordingly a groove 5 cm. wide was turned eccentrically in the large tube near the open end, so that the groove was 2 mm. deep on the top of the tube and 3 mm. deep on the bottom. When finally mounted a current was passed through the instrument and equipotential surfaces laid off on the tube. By a small amount of filing the eccentricity of the groove was adjusted so that the equipotential surface was a plane perpendicular to the axis. It was found that the relation held very accurately throughout the length of the tube—the distances between equipotential surfaces measured at different points on the circumference differed but one millimeter in 900.

From the principle of axial symmetry outlined above, it may easily be seen that no error due to skin effect in the closed end will enter. For this reason the moving coils were placed one third of the length from this end so as to minimize the effect of the leading-in cables, etc. Perhaps a fourth or even a fifth would have been better.

PERFORMANCE

It is of first importance to determine whether the instrument is affected by distribution errors. Rosa has described an indirect method[4] for making this determination by the use of capacity in the moving coil circuit. If the moving coil circuit be short circuited on a resistance shunted by a condenser having such a value that

$$L = C R^2$$

where L is the self-inductance, R the external resistance and C the capacity shunted around it, then there should be no deflection on closing the circuit, no matter what the position of the coil. But if there is such an error then there will be a residual deflection.

When the instrument was first set up it showed no such error up to 300 cycles. But after it had been in service some time this same test showed a slight error. This was found to be due to an extremely slight flexure of the inner tube brought about by clamping heavy cables and lugs to the massive terminals, although considerable care had been taken to obtain a secure mounting. The trouble could be removed by springing the tubes by means of clamps placed on the copper slabs which serve as terminals. In other words a slight departure from the condition of axial symmetry introduces a distribution error, and this can easily be detected and corrected by a purely electrical test. Strong clamps and struts, (shown in dotted lines in the figure), have been arranged to hold the copper slabs in proper position.

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[4] *Bulletin of the Bureau of Standards*, 3, p. 43, 1907. *Reprint* No. 48.

Measurements of large currents by means of a current transformer whose ratio had been carefully determined were in substantial agreement with the indications of the .tubular dynamometer. It is believed that the instrument is accurate to 0.05 per cent.

It was found necessary to put loose-fitting diaphragms across the tube on each side of the moving coils to prevent air currents, for such currents of air caused considerable unsteadiness of the reading, even for comparatively small temperature differences in the mass of copper composing the instrument. The diaphragms effectually removed the trouble.

A more serious difficulty was encountered with magnetic impurities in the moving coil. The requirements here are even more exacting than in the sensitive moving coil galvanometer, for the parts of the moving coils nearest the inside tube are in a field comparable in magnitude to the flux in the air gap in the permanent magnets of such galvanometers. The whole directive magnetic force exerted on the coil must be vanishingly small or the zero of the instrument will not be the same with current on that it is with current off. In the galvanometer, on the other hand, the requirement is merely that the magnetic force on the coil shall not vary appreciably through comparatively small angles.

Finally special coils were wound which were entirely satisfactory. These were of silver wire 0.2 mm. in diameter, silk covered, and were stated by Mr. W. N. Goodwin, Jr., of the company which made the coils, to be actually diamagnetic.[5]

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[5] Mr. Goodwin found the torque acting on the coils and tending to maintain them at right angles to a magnetic field having a strength of 1,175 gausses to be 0.286 and 0.238 dyne-centimeters per radian respectively.

They were mounted with great care to prevent magnetic contamination from dust. The zero is precisely the same with current on or off.

It might have been better to have made the instrument with two independent sets of moving coils, one set for the smaller currents placed very close to the inside tube where the field is strongest, perhaps even decreasing the diameter of the tube for the purpose, and a second set for heavier currents placed near the outer tube. This would extend the range of the instrument. In addition, current and power could be measured simultaneously.

CONSTANTS AND DIMENSIONS

Copper slabs for current terminals:		
Thickness	2.5	cm.
Width	20	"
Outer tube:		
Length	101	cm.
Radii	6.41 and 7.07	"
Inner tube:		
Length	126	cm.
Radii	1.03 and 1.66	"
Total weight of instrument (approximately) 80 kg.		
Moving coils:		
Diameters (approximately)	2.5 and 5	cm.
116 turns of 0.2 mm. silver wire		
Weight of each coil	7.3	g.
Moment of inertia, each	12	g.—cm.^{2}
Resistance:		
Coils alone	12.2	ohms.
Total for system	14.4	"
Self-inductance	1.4	mh.
Resistance:		
Outer tube	8	microhms.
Inner tube	42	"
Complete instrument	53	"
Power consumed (*at* 5,000 *amperes*):		
Outer tube	200	watts
Inner tube	1,050	"
Complete instrument	1,325	"
Magnetic field at center of coils (approximately)	300	gausses
Sensitivity:		
100 cm. deflection at 86 cm. scale distance requires 100 amperes with 0.06 amperes in the moving coil.		
Capacity:		
With water cooling	5,000	amperes
Without water cooling	1.200	"
Of moving coil circuit	0.06	"

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MEASUREMENT OF ALTERNATING CURRENT OF LOW VALUE

BY M. G. NEWMAN

Alternating-current ammeters of the dynamometer type when used for measuring small currents are usually connected so that the moving coil is in series with the stationary or field coils. As the instrument has no iron in its magnetic field, the instantaneous values of the flux densities in the moving and fixed coils will be proportional to the current. The torque will, therefore, be proportional to the square of the current and the instrument will indicate the effective value of the current.

In order to increase the sensibility of the ammeter, suspensions are used in place of pivot and jewel bearings. The weight of the moving parts and the size of the suspension are made as small as possible without having the period too long or the instrument too much affected by external disturbances.

The determination of small alternating currents is usually required in circuits of low voltage. It is, therefore, necessary that the impedance of the ammeter shall be small, as the voltmeter reading must include the potential drop in the ammeter,

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REFERENCES

"Study of the Current Transformer with Particular Reference to Iron Loss," by P. G. Agnew; National Bureau of Standards, Reprint No. 164.

Electrical Measurements on Circuits Requiring Current and Potential Transformers, by L. T. Robinson, TRANSACTIONS, A. I. E. E., 1909, XXVIII, II, p. 1005.

National Bureau of Standards, Reprint No. 130, "The Determination of the Constants of Instrument Transformers," by P. G. Agnew and T. T. Fitch.

and this should be negligible within the limits of accuracy required by the test.

In examining an ammeter for sensibility, two things should be considered, the ampere sensibility and the impedance.

The square of the current multiplied by the impedance of the instrument gives the volt-amperes. If the weight of the moving coil and size of the suspension have been reduced to the minimum limit, the ampere sensibility can only be increased by increasing the number of turns in the coils; but if the size and weight of the coils are kept the same, the resistance and inductance of the instrument will increase approximately with the square of the number of turns.

The voltage necessary to give a deflection of a certain amount, therefore, will increase as the current sensibility is increased. Thus for very low reading ammeters the impedance is high, and if measurements are to be made in a circuit of low electromotive force the error in the voltmeter reading, due to the potential drop in the ammeter, will be considerable.

Separately Excited Dynamometers. By separately exciting one of the elements of the ammeter by current from a phase shifting transformer, the sensibility of the instrument is very much increased. Its deflection then is proportional to the product of the amperes in the moving and fixed coils times the cosine of the phase angle between them.

The instrument is calibrated as a wattmeter.

$W = k\,r\,d$, where **(1)**

W = watts
r = total resistance in the potential circuit
d = the deflection
k = constant of the instrument

The phase position of the current in the separately excited element is changed by the phase shifting transformer until the reading of the instrument is a maximum.

In the equation: $W = E\,I$ cosine θ **(2)**
If θ is zero, $W = E\,I$

Wave Distortion by Phase Shifting Transformer. The angle of shift of the secondary potential of the phase shifting transformer is determined by the position of the secondary winding relative to its primary winding, and is independent of the frequency. If the impressed wave is not sinusoidal, there will be a distortion due to the fact that each harmonic wave which makes up the complex wave is shifted the same number of degrees; but each with reference to its own length and not to that of the fundamental. For this reason it is better, in general, to use an approximate sine-wave generator.

There may also be present a small wave distortion due to the leakage reactance of the phase shifting transformer. This, however, is very small and in general may be neglected.

Errors Due to Wave Form. If the wave form of the currents in the two elements of the dynamometer is the same, the above equation (**2**) is strictly correct, but this is seldom the case. A brief discussion of the errors of the method is necessary.

Harmonics of current present in only one element of the instrument produce no torque. Taking an example: consider a sine current wave in the potential circuit of the dynamometer, and in the current coil, a current wave with a fundamental, the effective value of which is 10 amperes, and a third harmonic with an effective value of 1 ampere: the effective value of the complex wave will be $\sqrt{10^2 + 1^2} = 10.05$ amperes, but the dynamometer will measure only the fundamental and the error will be 0.5 per cent.

If harmonics other than the fundamental are present in both elements, torque will be produced by those of the same frequency which may be either negative or positive, the sign and magnitude depending upon the phase position of the harmonics.

As the errors pointed out above depend upon the wave shapes of the current in the two circuits of the dynamometers, it is impossible to make corrections without knowing the wave forms.

The following current measurements were made to investigate the errors of the method and a comparison was made with the readings of a dynamometer ammeter which was used as a standard.

TESTS

Exciting current tests were made on a telephone transformer at 60 cycles:

(a) Using the separately excited dynamometer as an ammeter. The diagram of connections is shown in Fig. 1.

(b) Using the dynamometer ammeter with connections as shown in Fig. 2.

Power was supplied from a three-phase Thomson-Houston smooth-core alternator. The potential waves are given in Curve 1.

The voltage of the generator is 575 at 60 cycles, and was stepped down through 5:1 step transformers with their primaries and secondaries connected in delta.

With the amplitude of the complex wave taken as **100**, the following amplitudes of the harmonics were obtained by analysis:

Amplitude of the fundamental	99.34
" " " 3rd harmonic	0.25
" " " 5th "	1.44
" " " 7th "	0.71
" " " 9th "	0.44
" " " 11th "	0.21

A one-ampere reflecting dynamometer wattmeter was used separately excited. The resistance of the current element of this instrument is 4.8 ohms. The resistance of the moving coils, including suspension and spiral, is about 30 ohms. The constant of the instrument when expressed by equation (**1**) is approximately 7×10^{-7}, where d is the deflection in mm. with the scale one meter distant from the mirror.

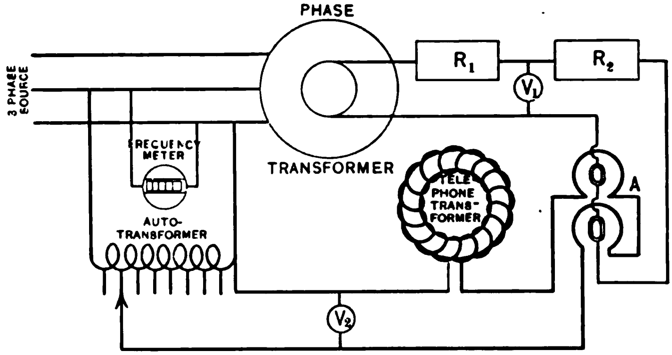


FIG. 1.—DIAGRAM OF CONNECTIONS.

The moving element of the instrument was separately excited, as is shown in Fig. 1, and the current was maintained constant by means of an adjustable non-inductive resistance (R_1) and voltmeter (V_1).

The voltage on the telephone transformer was changed by changing the taps on the auto-transformer. The excitation of the generator was held constant. The voltage applied to the telephone transformer was measured by (V_2). This included the potential drop in the current coils of dynamometer, which was negligible.

The tests were repeated using a reflecting voltmeter as an ammeter, with connections as given in Fig. 2. The resistance of this instrument is 60 ohms with the stationary coils connected in parallel, and in series with the moving coil. The instruments were calibrated by potentiometer with direct current.

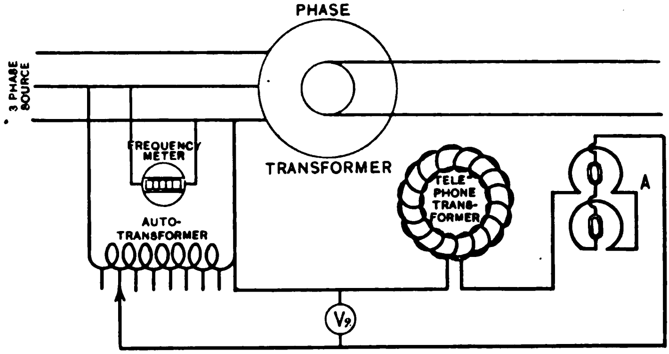


FIG. 2.—DIAGRAM OF CONNECTIONS.

TABLE I

EXCITING CURRENT OF TELEPHONE TRANSFORMER AT 60 CYCLES

Ammeter method			Separately excited dynamometer method		
Flux density lines per sq. cm.	Volts	Amperes	Flux density lines per sq. cm	Volts	Amperes
328	22.2	0.00357	346.8	23.48	0.00382
406	27.5	0.00402	416.5	28.2	0.00400
488	33.05	0.004425	490.5	33.2	0.00442
569	38.5	0.00475	560	37.9	0.00469
650	44	0.00505	632	42.8	0.005015
730	49.4	0.00537	694	47	0.00525
811	54.9	0.00554	765	51.8	0.00547
892	60.4	0.00580	834.5	56.5	0.005612
961.5	65.1	0.00595	978	66.2	0.005932

The results of tests are given in Table I and Fig. 3.

On the average, the agreement of the two sets of readings is close, but variation in individual readings is considerable. It is believed that this trouble may have been due to the unstable magnetic properties of iron at low densities. It would have been better to have connected the instruments so that the measurements could have been made simultaneously.

The above tests cover a range of densities from 300 to 900 lines per sq. cm. In order to carry the measurements to higher densities and to obtain larger values of current so that oscillograph records could be taken, additional measurements were taken on a 20-lb. (9.07-kg.) core of high silicon steel made up of 7 by 10 by 0.014 in. ring punchings.

This core was wound with 140 turns of No. 12 B. and S. gage copper wire, the resistance of which was about 0.1 ohm.

A diagram of connections is given in Fig. 4. Portable instruments were used altogether in taking readings on the 20-lb. core.

A potential of 100 volts was impressed upon the potential coil of the wattmeter. The readings of the wattmeter were divided by 100 to obtain the current readings given in Table II, column 4.

It can be seen from Fig. 4 that the current in the voltmeter (V_2) was included in the reading of the ammeter, but as this was not a test on the iron, it was unimportant.

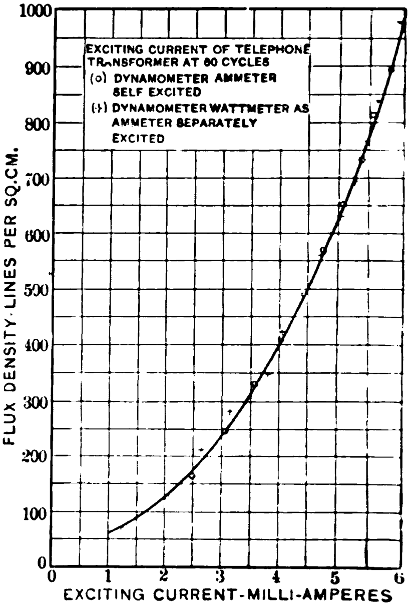
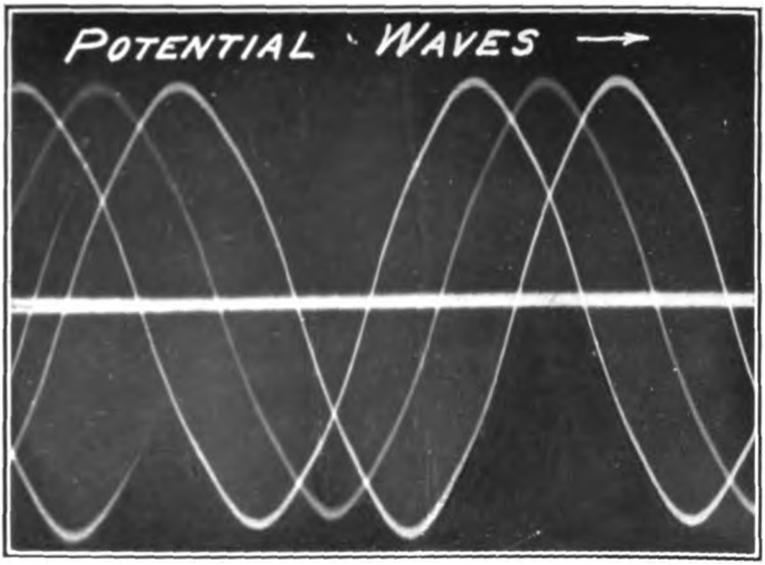


FIG. 3

The method of procedure was the same as before. The phase shifting transformer was adjusted until the reading of the wattmeter was a maximum. The voltage on the potential coil was then adjusted to read 100 and A, V_2 and W were read.

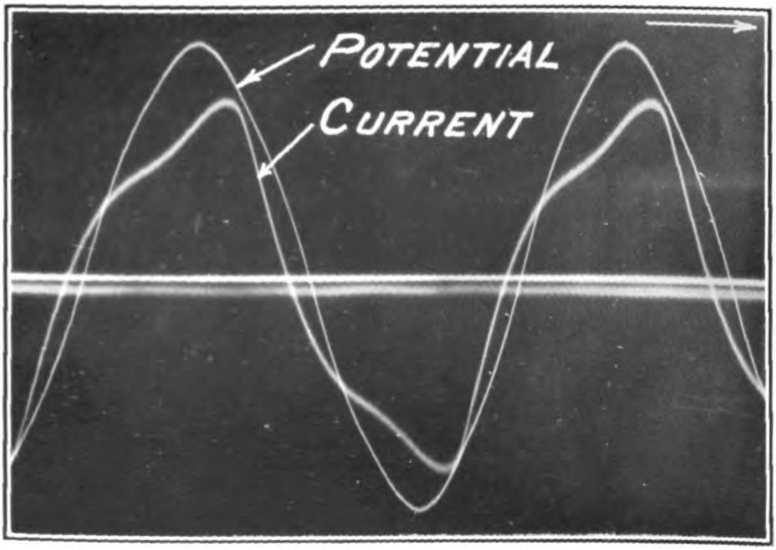
The results are given in Table II and Fig. 5.

From Fig. 5, it is seen that below a density of 6,000 lines per sq. cm. the error is very small. Curves 2 and 3 show the exciting current, and the potential waves impressed upon the wattmeter from the phase shifting transformer. Curve 2 was taken at 5,090 lines per sq. cm. The effective value of the ex-



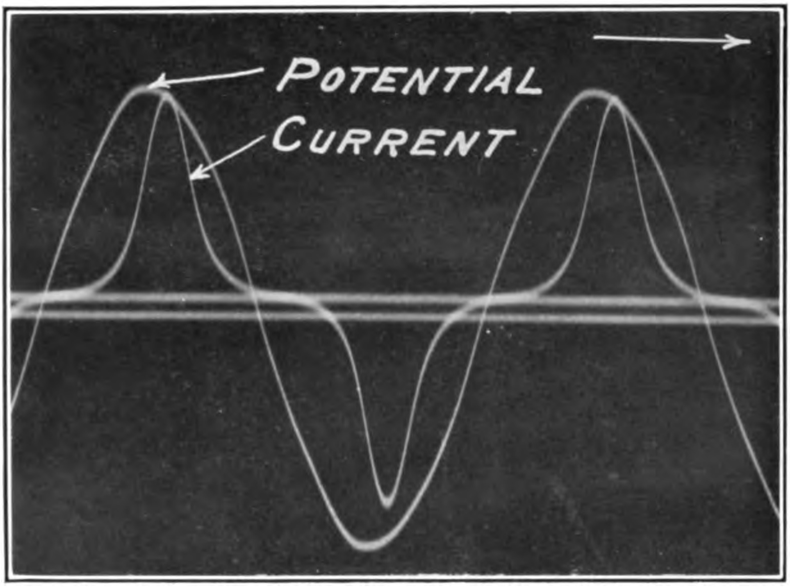
[NEWMAN]

CURVE 1.—POTENTIAL WAVE OF THREE-PHASE THOMSON-HOUSTON GENERATOR AT NO LOAD—60 CYCLES.



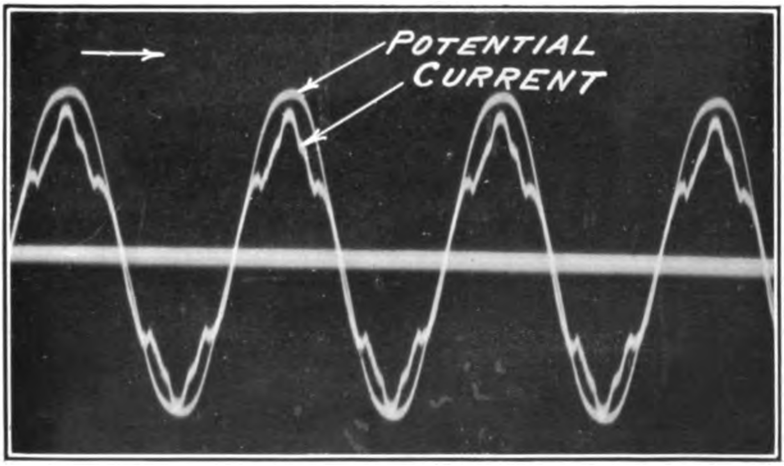
[NEWMAN]

CURVE 2.—POTENTIAL WAVE OF PHASE SHIFTING TRANSFORMER AND CURRENT WAVE IN MAGNETIZING WINDING OF RING SAMPLE AT 5090 LINES PER SQ. CM.



[NEWMAN]

CURVE 3.—POTENTIAL WAVE OF PHASE SHIFTING TRANSFORMER AND CURRENT WAVE IN MAGNETIZING WINDING OF RING SAMPLE AT 15,400 LINES PER SQ. CM.



[NEWMAN]

CURVE 4.—POTENTIAL WAVE OF PHASE SHIFTING TRANSFORMER AND CHARGING CURRENT WAVE OF CONDENSERS.

citing current was 0.271 amperes. Analyses of the current and potential waves give the following results:

(The amplitude of the harmonics is expressed in percentages of the amplitude of the complex wave.)

	Current	Potential
Fundamental	94.1	98.0
3rd harmonic	17.1	0.9
5th "	3.82	2.0
7th "	1.77	negligible
9th "	1.58	0.4
11th "	0.88	0.4

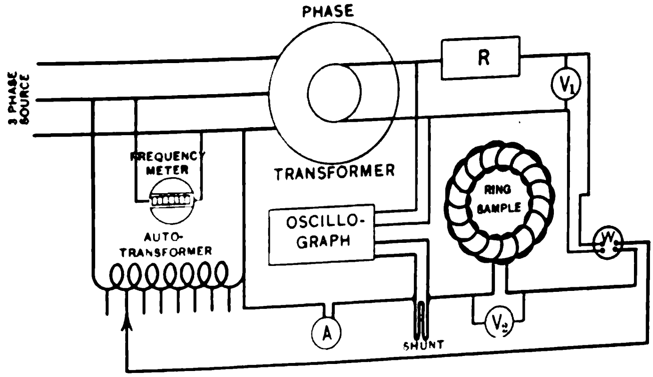


Fig. 4.—Diagram of Connections.

The effective values of the harmonics of the current are given below:

	Effective amperes
Complex wave	0.271
Fundamental	0.266
3rd harmonic	0.048
5th "	0.010
7th "	0.005
9th "	0.004
11th "	0.002

Assuming that no torque is produced by the harmonics in the current wave, an error of 1.8 per cent will be introduced. This agrees very closely with results obtained by tests.

Curve 3 was taken at a density of 15,400 lines per sq. cm. The effective value of the exciting current was 4.85 amperes.

The analysis of the current wave gives the following results:

TABLE II

EXCITING CURRENT OF RING SAMPLE OF HIGH SILICON STEEL AT 60 CYCLES

Flux density lines per sq. cm.	Volts	Exciting current—amperes		Error	Reading of phase shifting transformer
		Ammeter	Separately excited dynamometer	Per cent	Degrees
812	5.39	0.0902	0.0885	1.9	45
2,542	16.88	0.1665	0.1642	1.4	45
3,300	21.9	0.1948	0.191	1.9	45
3,375	22.4	0.1975	0.197	0.25	45
4,200	27.9	0.232	0.2279	1.75	48
5,090	33.8	0.271	0.2667	1.5	48
6,070	40.3	0.321	0.3183	0.85	48
6,900	45.8	0.372	0.363	2.4	52
8,610	57.17	0.506	0.4895	3.2	52
9,520	63.2	0.614	0.589	4.0	53
10,120	67.2	0.692	0.659	4.7	53
10,950	72.66	0.851	0.794	6.7	55
11,930	79.16	1.086	1.019	6.2	58
12,780	84.85	1.396	1.257	10.0	58
13,950	92.6	2.2	1.88	14.5	60
14,800	98.3	3.49	2.815	19.3	60
15,400	102.2	4.85	3.91	19.4	64

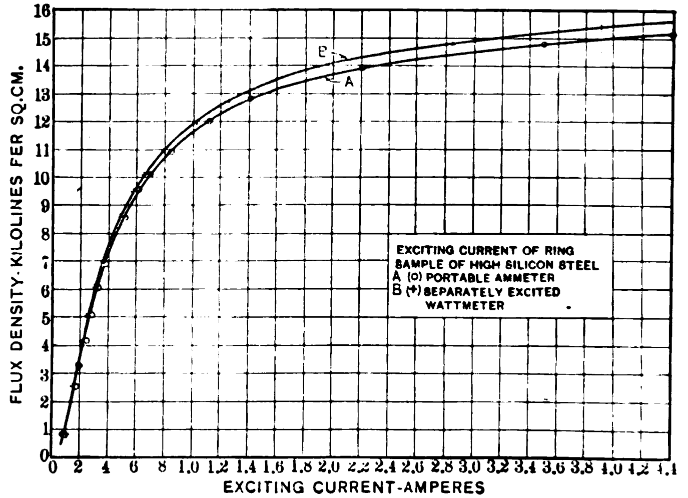


FIG. 5.—EXCITING CURRENT OF RING SAMPLE OF HIGH SILICON STEEL AT 60 CYCLES.

(the amplitude of the harmonics is given in percentages of the amplitude of the complex wave)

	Current
Fundamental	49.6
3rd harmonic	23.9
5th "	10.9
7th "	4.5
9th "	1.6
11th "	0.2

The effective value of the fundamental in this case is 4.05 amperes, which would, if the potential wave from the phase shifting transformer were sinusoidal, make an error of 16. 5 per cent in the results.

The actual tests gave 3.91 amperes or an error of over 19 per cent.

Measurements of Capacity Current of 0.5-*Microfarad Condensers.* Readings given in Table III were made by the separately excited dynamometer and by the dynamometer-ammeter.

TABLE III

CAPACITY OF MICA CONDENSER AT 60 CYCLES BY SEPARATELY EXCITED DYNAMOMETER AND BY AMMETER METHODS

Volts	Amperes	Micro-farads
	By dynamometer	
100	0.00184	0.4855
80	0.00183	0.485
108.8	0.001848	0.488
	By ammeter	
101.6	0.00946	0.4935

The values of capacity were calculated from the current readings using the following formula, which is for a sine wave:

$$C = \frac{I}{2\pi f E}$$

The difference in the results by the two methods is less than 2 per cent.

The condenser previously measured at 0.6 sec. charge and 1 sec. discharge by ballistic galvanometer gave a capacity of 0.4990 microfarad.

Sensibility of Separately Excited Ammeter. In order to obtain comparative measurements, it was necessary to use currents of comparatively large value. For this reason the one-ampere coils were used in the wattmeter dynamometer.

By varying the excitation of the moving coil, it is possible to make current measurements over an enormously large range without changing the current coils.

The sensibilities of the instrument with different field coils are given below:

Rated current carrying capacity	Resistance	Amperes	Deflection
0.17 amperes	154.0 ohms	3×10^{-5}	10 mm.
1.0 "	4.8 "	2×10^{-4}	10 "
3.0 "	0.53 "	1×10^{-3}	10 "

By using the stationary coils as the separately excited element with full excitation, the following sensibilities may be obtained:

	Resistance	Amperes	Deflection
500-turn moving coil	400 ohms	3×10^{-7}	10 mm
65- " " "	65 "	3×10^{-6}	10 "

From the above values it is seen that an ammeter of very great sensibility is easily obtained. It has the advantage over a great many high sensibility ammeters, in that the suspension and moving parts are comparatively rugged, and the instrument is not easily troubled by outside disturbances.

Discussion of Results

It has been shown by the above tests that comparatively large errors may occur if the separately excited ammeter is used to measure the exciting current of sheet steel at high densities.

The complex exciting current wave may be considered to be composed of a sinusoidal component and a distorting component. At high densities this distorting component is large and the sinusoidal component is small in comparison. This large distorting component is due to the rapid rate of change of reluctivity during the magnetic cycle. At extremely low magnetic densities the reluctivity may be even higher than that above the knee of the curve, but the distorting component is not great because the reluctivity remains more nearly constant. As the density is lowered the exciting current wave approaches the sinusoidal form.

The results of test indicate that below a density of 6,000 lines per sq. cm., the errors obtained when using the separately excited dynamometer do not exceed 2 per cent. The results are always low since harmonics other than the fundamental produce no torque. The total range of measurements covered densities from 300 to 15,000 lines per sq. cm.

Of course, the wave distortion will vary with different samples of steel, depending upon the shape of the saturation curve.

CONCLUSIONS

The sensibility of a dynamometer-ammeter is greatly increased by separately exciting one element from the phase shifting transformer.

Large errors are introduced when such an instrument is used to measure exciting current of sheet steel at high densities.

Measurements may be made of the exciting current of sheet steel at densities below 6,000 lines per sq. cm. with very small error.

Because of the limited time available for making these tests several parts of the original outline had to be omitted, but although the investigation is limited and incomplete the usefulness of the method is apparent for measuring exciting current of sheet steel at low densities.

The writer wishes to acknowledge the great assistance rendered by Mr. F. Dakin in making the tests and preparing this paper.

A paper to be presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

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ELECTRICAL MEASUREMENTS WITH SPECIAL REFERENCE TO LAMP TESTING

BY EVAN J. EDWARDS

Perhaps there is no kind of testing for commercial results that requires more accurate electrical measurements than the testing of incandescent lamps. All incandescent lamps are very sensitive to changes in the electrical conditions of the circuit. A change of 1 per cent in pressure brings about a change of 5.7 per cent in luminous intensity for carbon lamps and 3.7 per cent for tungsten filament lamps. There is a corresponding change in the life, but of a magnitude four to five times as great.

An average deviation of luminous-intensity readings of 0.4 per cent from the arithmetical mean is obtainable with good photometric apparatus, calling for a voltage accuracy of 0.1 per cent in the same precision measure. 0.1 per cent is generally considered good enough for life testing also, even though the life is affected more than the luminous intensity by a given change in pressure, the justification being that the individual variation, inherent to a group of supposedly similar lamps, is considerable.

It seems safe to say that photometric and lamp testing laboratories should maintain an accuracy of 0.1 per cent in their electrical measurements, that is, the electrical measurements should furnish results which have little probability of being in error by more than 0.1 per cent. Not only should the instruments be capable of better than 0.1 per cent accuracy in reading, but also calibrations should be sufficiently accurate and frequent and with sufficiently well established standards to insure an accuracy of 0.1 per cent in the final result.

It may be of interest to consider the things upon which ultimate electrical accuracy depends and the methods made use of, in the engineering department of the company with which the writer is connected, for obtaining this desired degree of electrical accuracy.

The accuracy of electrical measurements may be said to depend first on the accuracy of the instrument, and second on the care and skill exercised by the observer.

An investigation of instrument accuracy involves first the testing of the mechanical characteristics. A voltmeter must have a friction drag of less than the accuracy desired in the result in order that it may be safe and convenient to use. The electrical and mechanical characteristics must be such that the reading corresponding to a given pressure is closely the same throughout a range of temperature and change in position such as will be encountered in use. Also, the process of calibration and the basic standard must be of sufficient precision. A careful comparison with a potentiometer, using standard cells of proved accuracy, taking readings up and down scale and for both directions of current, combined with a close inspection, furnishes a complete test of the instrument. Fig. 1 shows results from a test on an a-c. instrument.

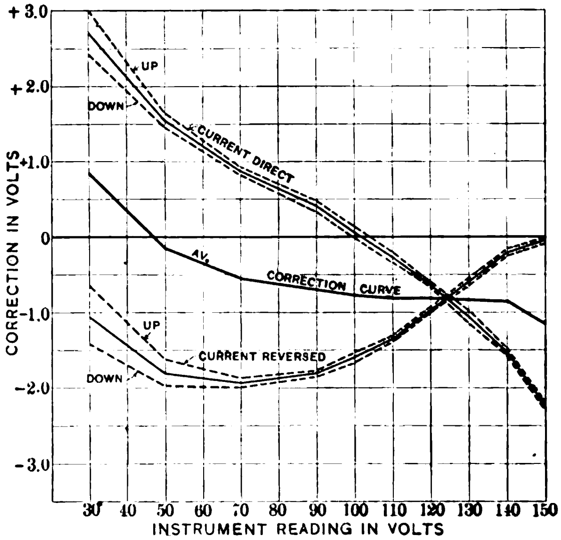

Fig. 1.—Calibration of Laboratory Standard Alternating-Current Voltmeter No. 33.

Surely all electrical instruments in a lamp testing laboratory should be tested periodically and, moreover, it is desirable that the results be recorded in chronological order. The advantages of maintaining a record are self-evident. All instruments in the engineering department are calibrated periodically according to a fixed schedule and the results are recorded in a graphical form which furnishes at a glance the past history of the instrument. The frequency of calibration depends upon the use to which the instrument is put; for example, a laboratory standard alternating-current voltmeter used for checking the voltage on the life test racks is checked with the potentiometer daily. The curve of Fig. 2 shows the record of this particular instrument, over the past six months. Since this instrument is maintained at nearly constant temperature, being in continuous service, and is undisturbed in position, it is interesting to note that the record is what may be termed a life curve of the dynamometer type of the instrument. The change of calibration is no doubt due to the weakening of the spring.

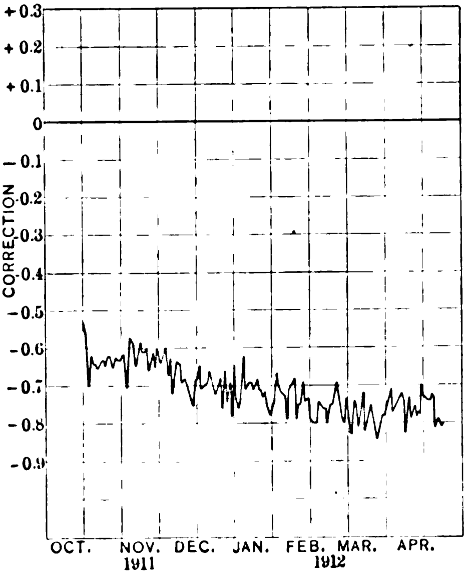

FIG. 2.—CALIBRATION OF LABORATORY STANDARD ALTERNATING-CURRENT VOLTMETER AT 120-VOLT POINT.
Voltmeter No. 33.

A new standard cell is obtained regularly twice per year, in addition to others obtained as needed. Two are kept apart at all times as reference standards and are used only for checking the cells used regularly on the potentiometers. This program in connection with the continuous graphic history in the calibration of a large number of instruments, practically eliminates all possibility of error or drift in the value of the unit used as a basis for the laboratory work.

The subjective factor which enters into meter reading is an important one and one seldom given sufficient attention. Aside from the ordinary care and judgment required in the use of electrical instruments, the accuracy depends on the skill of the observer in precise reading. The reading involves two kinds of subjective errors, the accidental or indeterminate such as occur in all measurements, and the error due to a mistaken idea as to the scale position corresponding to the various tenths between smallest division. Among untrained observers there is also a favoritism shown for certain digits, as is shown by Fig. 3, which records the percentages of various digits representing the estimation of tenths for a large number of readings for one particular observer who has a preference for certain digits, especially zero.

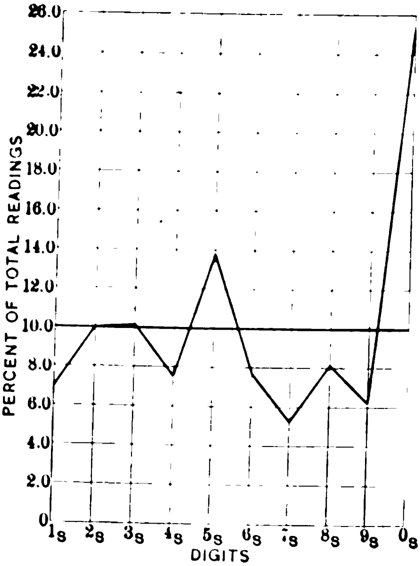

FIG. 3.—ESTIMATION OF TENTHS

Test A—600 readings.

Fig. 4 shows two meter setting curves which were obtained by averaging the curves for a large number of observers, and which are fairly typical. The deviation of the "setting" curve from the straight line is a measure of the error in the average observer's idea as to the position of the various tenths, and the deviation curve is a measure of the accuracy which the average observer can attain in the setting of the pointer in the position which he thinks is the correct one. No doubt the setting curve is what would be expected, the positions between five tenths and ten tenths being in error by about the same amount as those from zero to five tenths, but in the opposite direction, showing that the average observer obtains the upper values by subtracting a certain distance from the upper line, in the same manner that he obtains the lower ones by adding the same distance to the lower line. The five-tenths point is about right, as would be expected. Tests have shown that various observers show vastly different but reproducible characteristics both from the standpoint of error in idea as to position and error in precision of setting. This is especially true of the precision of setting. Some have a low average deviation from the mean for the line and midway positions and others at the intermediate values. This test is valuable in that it furnishes a measure of both the directional and unavoidable errors to be expected; more than that, it allows the observer to correct his mistaken idea which previously was not known to be in error.

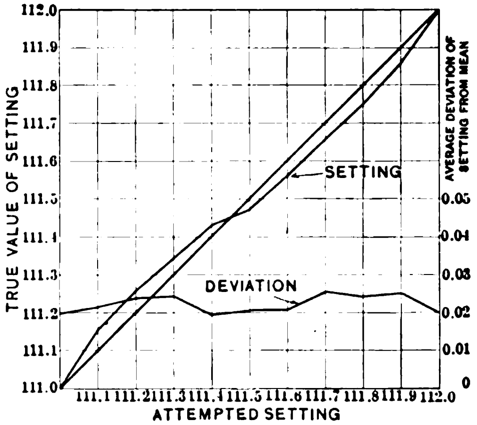

FIG. 4.—PRECISION OF METER READING.
Estimation of tenths between smallest divisions.

It was found that for every-day use on photometric equipment, the precision attainable with portable instruments was not sufficient to furnish the desired accuracy, and as a result large laboratory standards and deflection potentiometers were substituted. The scales of these can be, in most cases, read to the nearest 0.1 per cent without estimation of tenths.

The indicating instrument used for the continuous observation of life test voltage, at the laboratory with which the writer is connected, is an interesting feature in itself, apart from the laboratory standard used for periodic comparisons. It is well known that a switchboard operator prefers an instrument to which no calibration correction need be applied, that is to say he prefers to adjust the voltage to a line which is labeled as the voltage at which he is instructed to run. This feature of the subjective problem finds no application in most laboratory precision work, but is worthy of consideration in this particular instance as in central station operation where a constant condition of operation is desired.

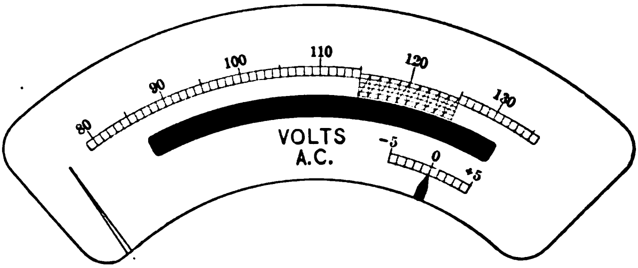

Fig. 5

It is well known that no instrument can be made which will maintain a zero correction, even though initially adjusted very carefully to that value. Many instruments on the market can be made to read correctly at one point on the scale by shifting the zero point by means of the adjustment of the spring. Such instruments are difficult of accurate adjustment, however, and moreover furnish no means of recording the calibration for a history of the performance of the instrument. Fig. 5 shows the scale of the instrument designed to overcome this difficulty. The scale can be shifted by means of a rack and pinion at the top (not shown) to the proper point to make the indication correct at the 120-volt point, the one used in this case. The calibration is indicated by the stationary pointer near the bottom of the scale. The instrument is calibrated daily and the correction recorded, and when the trend of the calibration curve shows a drift of more than 0.05 volts the scale is shifted and the new reading of the stationary point is made a new addition to the history of the instrument.

This instrument is of the dynamometer type, air-vane-damped and practically free from jewel friction. It has been in service only a short time, but promises to fulfil the requirements very well.

A graphic recording voltmeter is used in connection with the indicating instruments, and cannot be depended upon as a precision instrument due to the comparatively large friction in the movement and the tendency to wear a rut, so to speak, in the movement, at the one point where it is constantly used. It is useful only in that it records any comparatively large change which might take place, and the time at which service is interrupted and resumed.

All must agree that in a photometric and lamp testing laboratory a great deal of thought and much time must be continually applied to the question of electrical measurements in order that those in charge may be assured that the desired accuracy is maintained at all times.

A paper to be presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 28, 1912.

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(Subject to final revision for the Transactions.)

MEASUREMENT OF ENERGY WITH INSTRUMENT TRANSFORMERS

BY ALEXANDER MAXWELL

A good deal has been written concerning the determination of the ratio and phase angle of instrument transformers, and several methods are now available which are of good accuracy. Also, there is considerable matter available regarding the design of such transformers, with reference to the production of satisfactory ratio and phase angle characteristics. Comparatively little has appeared, however, concerning the effect of ratio and phase angle upon the accuracy of watt-hour meters.

The effects of ratio and phase angle upon the indications of switchboard instruments can generally be provided for without much difficulty, and where these effects become important in connection with special measurements made with portable instruments, such as precise measurements over a wide range of currents or voltages, or at low power factors, correction may readily be made for them, the only requirements being a knowledge of the ratio and phase angle characteristics of the particular transformers used, and some rather tedious calculations.

With watt-hour meters, however, the problem is more difficult. It is not possible to adjust such meters to automatically compensate for changes in ratio and phase angle for different loads and different power factors within the range of the meter. Legal and commercial considerations require that such meters be maintained within certain specified limits of accuracy. It is the purpose of this paper to consider, briefly, some aspects of the problem presented by the use of instrument transformers in connection with watt-hour meters.

POTENTIAL TRANSFORMERS

Deviations from stated ratio and ideal phase relation are small in potential transformers, as compared with current transformers. Furthermore, in a large majority of cases, potential transformers are used in connection with constant potential systems, and at constant secondary load, and therefore the determined values of ratio and phase angle for that particular load remain unchanged. Ratio may be taken into account once for all in the calibration of the meter. Phase angle may not be compensated, except for a particular value of load power factor, as shown later, but in most cases the error due to this deviation from the ideal phase relation will be negligibly small.

CURRENT TRANSFORMERS

Generally speaking, modern current transformers of the best design, under favorable conditions of use, show quite satisfactory ratio curves for secondary currents down to 10 per cent of rated current. Similarly, the angle by which the secondary current differs from the ideal 180-deg. relation with the primary current is small over a quite wide range, but may still introduce serious errors at low loads.

Current transformers of special design, such as those intended for portable use, or in other cases where special efforts are made to reduce the weight of the transformer, generally have ratio and phase angle characteristics which render them quite unsuitable for use in connection with watt-hour meters.

Ratio. Where current transformer ratios have the same value from full secondary load to a small secondary load such as 5 or 10 per cent, the meter accuracy is not affected, since this ratio, whatever its value, is accounted for in the calibrating constant of the meter.

Where the ratio curve bends upward at low loads, or in the occasional cases where it bends downward, as shown in Fig. 1, the meter accuracy is affected if some compensation is not provided.

It is possible to compensate within somewhat narrow limits for this variation in ratio, by utilizing the light load adjustment of the meter; that is, for the commonest case (ratio increasing with decreasing current) causing the meter to run slightly fast at light load, to compensate for the increase in ratio, which tends to make the meter under-record.

The obvious objection to this procedure is that it may cause the meter to creep. A number of experiments made on many different types of induction watt-hour meters indicated that such over-compensation might be carried out without any tendency toward creeping, up to amounts corresponding to 101 to 103 per cent of " normal " speed, and at 5 per cent load. Some results of such tests are shown in Fig. 2. It is true that these tests refer to rated voltages and frequency, but since the permissible range of compensation seems to be considerably greater than that required to correct for transformer ratio errors such as those shown in Figs. 2 and 3, it is possible that this method of compensation may be applied without disturbing the stability of the meter with respect to creeping. In cases where the transformer ratio curve bends downward at low load, it is of course very easy to adjust the meter to accommodate the ratio.

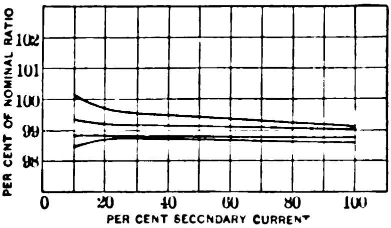

FIG. 1.—RATIO CURVES OF CURRENT TRANSFORMERS, ALL WITH MINIMUM SECONDARY LOAD.

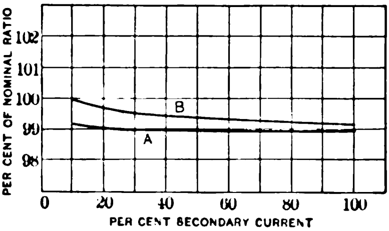

FIG. 2.—EFFECT OF LOADING CURRENT TRANSFORMER.
A—Watt-hour meter series coil only.
B—*A* plus ammeter and relay coil (about 60 per cent of rated volt-amperes.)

Another limitation of this method lies in the fact that transformer ratio curves are not always of the same form as the accuracy curve of the meter, and in this case, of course, complete compensation cannot be obtained. However, the most satisfactory current transformers have, when lightly loaded, ratio curves of the form shown by curve *A* in Fig. 3. The form of this curve reasonably approximates the form of the meter curves shown in Fig. 2. Curve *B* in Fig. 3, which is fairly typical of the change produced by loading the transformer, is of a form unsuitable for compensation. This indicates the desirability of restricting the load upon the secondary of the current transformer to a minimum, preferably the meter series coil and short leads only.

Phase Angle. Phase angle cannot be compensated by any means which will operate automatically. Since the meter torque depends upon $E\,I \cos(\theta + \phi)$ where ϕ is the transformer phase angle, the error will vary with the line power-factor, and since the transformer phase angle will vary with the current the error will also vary with the line current.

A few curves showing typical phase angle characteristics of modern current transformers of various types are given in Fig. 4. Fig. 5 shows the errors of measurement produced for various values of transformer phase angle, for different line power factors. These curves are computed for the condition where the secondary current leads the primary current in phase.

From Figs. 4 and 5 it will be seen that for ordinary commercial range of line power factors, the errors produced by transformer phase angle are comparatively small with transformers of good design. Where great accuracy is required, or where loads having low power factor are to be measured, errors due to this cause become troublesome. Apparently the remedy for this (besides selecting transformers having minimum phase angle) is to load the transformer as little as possible. Reactance may be added in the secondary circuit, to correct for phase angle, but only at the expense of the ratio. The writer's experience has been that, with several different types, the ratio errors have increased faster than the phase angle errors diminished, and the former finally became unmanageable. On the whole, it seems best to reduce phase angle as much as possible, by reducing the load upon the transformer.

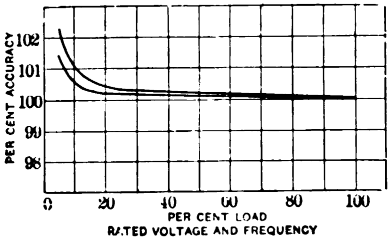

FIG. 3.—WATT-HOUR METER OVER-COMPENSATED BY MEANS OF LIGHT LOAD ADJUSTMENT.

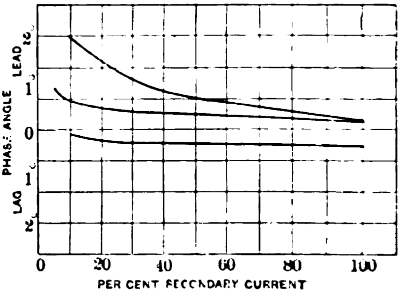

FIG. 4.—PHASE ANGLE, CURRENT TRANSFORMERS, ALL WITH MINIMUM SECONDARY LOAD.

A common difficulty, which constitutes another reason for supplying watt-hour meters, from separate transformers, lies in the practise of assigning over-size transformers for relay work. This over-size assignment is desirable, or necessary, for the relay, since the only function of the latter is to operate at overloads generally much greater than the normal load of the circuit, and it is important that the actual secondary current in the relay windings shall not attain excessive values. The result, however, where a meter is in series with the relay, is that the meter may actually be assigned at from one-half to two-thirds of its rated current and load; at very low loads on the circuit, corresponding to 5 or 10 per cent of rated circuit full load, the meter may actually be operating at 2 to 7 per cent of its rating, with all the attendant exaggeration of ratio, phase angle and meter errors.

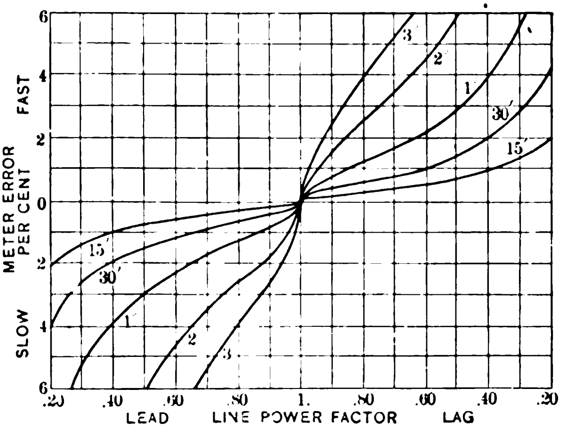

FIG. 5.—ERROR PRODUCED BY TRANSFORMER PHASE ANGLE, FOR VARIOUS LINE POWER FACTORS, SINGLE-PHASE OR POLYPHASE WATT-HOUR METERS.

A question of design arises in connection with transformers for use in power supply systems of great magnitude. Here it has been found that transformers of small primary capacity are unable to withstand the enormous mechanical forces produced on short circuit, and under these conditions they have been destroyed. This condition has called for the development of special types of transformers, and in these the necessity for preserving the desirable ratio and phase angle characteristics of normal designs results in a great increase in weight.

In conclusion, it may be said that the best commercial types of current and potential transformers show characteristics which make them satisfactory for service in connection with watt-hour meters, under ordinary conditions of use. It appears further that some sources of error may be at least partially compensated, and that the more serious errors may be largely avoided by loading transformers only with the meter which they supply. It is also true that very serious errors may be produced by the use of transformers having poor ratio and phase angle characteristics, and that such transformers should therefore not be used for energy measurements, however satisfactory they may be for less exacting service, such as the operation of trip coils or relays.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 28, 1912.

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INDUCTION TYPE INDICATING INSTRUMENTS

BY PAUL MACGAHAN

The modern switchboard, controlling as it does large amounts of power, and often situated where space is at a premium, demands a different type of switchboard instrument from that to be found on older switchboards. Moreover, modern generating equipments, generally turbine driven, have resulted in a readjustment of the comparative importance of the different kinds of electrical errors to which indicating meters are subject. For example, the frequency of a modern system does not usually vary more than one or two cycles from the normal speed, and therefore frequency characteristics are less important whereas formerly this was one of the great sources of error. Again, due to operation with larger currents or higher potentials, the external magnetic or electrostatic field effects are greatly increased.

The tendency of the designer should now be toward principles of operation or construction that are not greatly influenced by external fields instead of those free from frequency errors. In addition to this, the questions of compactness readability, aperiodicity, ruggedness, and simplicity are equal in importance to accuracy. Ordinarily the operator does not hesitate to repair or readjust a piece of electrical machinery, but due to the fact that early meters comprised " feather-weight " movements, delicate wires, pointers, and connections, the operators have developed a superstitious dread of breaking " seals " and making readjustments. The modern meters should be sufficiently rugged and simple to be readily handled by an operating company's " meter man."

VARIOUS PRINCIPLES OF OPERATION

For alternating currents the three principles of operation found in the best instruments today are as follows:

Moving Iron Electromagnetic Type. Good initial accuracy of calibration. Approximate freedom from frequency and temperature errors. Ratio of torque to weight—low. Some makes too delicate. Easy to repair. Subject to both alternating-current and direct-current external fields unless heavily shielded. Short scale length.

Moving Coil Electrodynamometer Type. Highest in initial accuracy of calibration and freedom from errors due to frequency and temperature. Ratio of torque to weight—low. Delicate. Difficult to repair. Subject to external fields of same frequency unless heavily shielded by internal laminated iron shields. Short scale length.

Induction Type. Good initial and continued accuracy. Ratio of torque to weight—very high. Rugged and simple movements. Easy to repair. Extremely long scales and high readability. Frequency errors greater than in moving coil or moving iron types. External field errors due only to fields of same frequency, in certain directions, and are slight.

Other principles have been from time to time employed, but the race has now narrowed down to the above three types.

The fundamental or distinctive advantage of induction instruments for switchboard use is their unequalled scale length. It should be borne in mind that the moving coil or moving iron meters, as now manufactured, evidently represent very nearly the highest state of development to which these principles can be brought, whereas in the case of the newer induction principle, much can be expected in the future in the way of greater refinements. It is the writer's opinion that the induction principle will eventually supersede the other types for switchboard work, for the same reasons that this principle has superseded all others in the case of a-c. watt-hour meters.

ACCURACY

Induction type instruments are especially free from external field influences. Nor are they as deficient in frequency error characteristics as is often assumed. Induction type ammeters and voltmeters having an error of less than 1/20 per cent per cycle are now obtainable, so the error due to this cause in a modern plant would not be noticeable.

Moving iron and moving coil instruments, although practically free from frequency and temperature errors when properly designed, are extremely subject to external field effects, and the best practice is to insert heavy shields of iron within the thin-iron cases to overcome this. Without such shields the thin iron cases quickly get saturated by an external field, after which the further shielding effect ceases. Their light torque also causes them to be very susceptible to external electrostatic effects which cause the pointer to be attracted to the glass or case, introducing troublesome errors. It should be noted that moving coil meters have an advantage over moving iron types in being influenced only by external magnetic fields of the same frequency; whereas moving iron meters are affected by both alternating and direct stray fields.

Temperature errors in instruments are important, as variations in the temperature of switchboards may be considerable. Alternating-current instruments of either induction, moving coil, or moving iron construction are readily obtainable whose temperature errors are within satisfactory limits. Self-heating errors due to heat liberated in the meters themselves should be carefully avoided, and are not found in properly designed meters.

The mechanical sources of error are probably of greater importance than purely electrical ones in switchboard instruments, as the causes which produce them also reduce the life of the device and greatly increase the errors with usage and time. Instruments having the highest ratio of torque to weight of movement will have the greatest accuracy and longest life if equivalent in other respects, and if the movement is not sufficiently heavy to damage the jewels. Experience and tests have shown that 15 grams maximum is a safe limit for horizontal shafts in " V " sapphire jewels, and that a ratio of torque to weight of 0.15 is a satisfactory minimum, when torque is expressed in centimeter-grams, and weight in grams, in the case of switchboard meters. The disadvantages of very light movements, even if the torque ratio be high, is that the slightest mechanical strain due to overload, or even precipitation of moisture on the pointer, will throw the movement out of balance; thus such meters must necessarily be provided with external means for zero adjustment. The exceedingly delicate threaded rods, screws, and other parts visible only under a glass, render such meters difficult to repair outside the factory.

Compactness

A form of construction considered desirable for these induction meters consists of a round pattern 7-in. diameter case with a glass front. The scale length is 14½ in., subtending an arc of 300 deg. This gives the maximum possible compactness and readability. A compact arrangement of large switchboard equipment is considered important on account of the cost of space (particularly in large cities), reduced attendance, location in operating galleries, reduced cost of marble or bus bars, and visibility of all instruments from point of operation. These features are of such importance that it is not unusual to find that the meters have been made to suffer in consequence by a reduction in scale length, as in previous types of 7-in. meters, or by the use of rectangular cases with curved glass, as in vertical or horizontal edgewise meters.

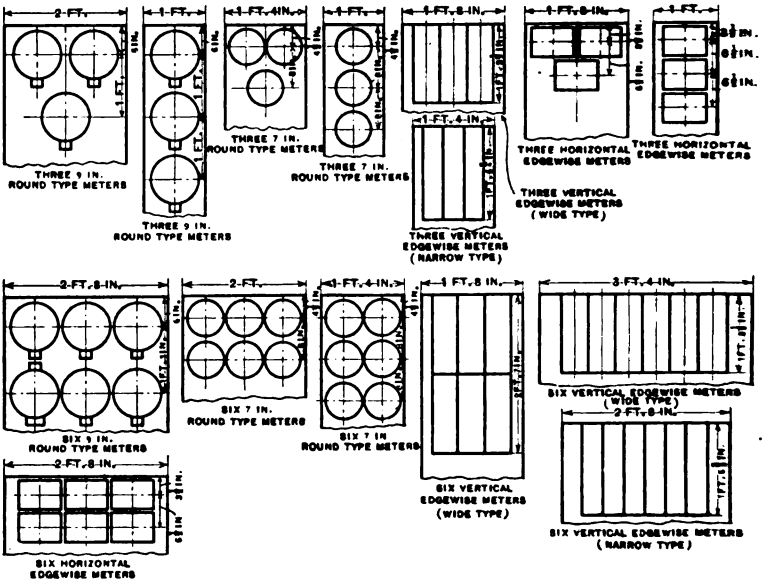
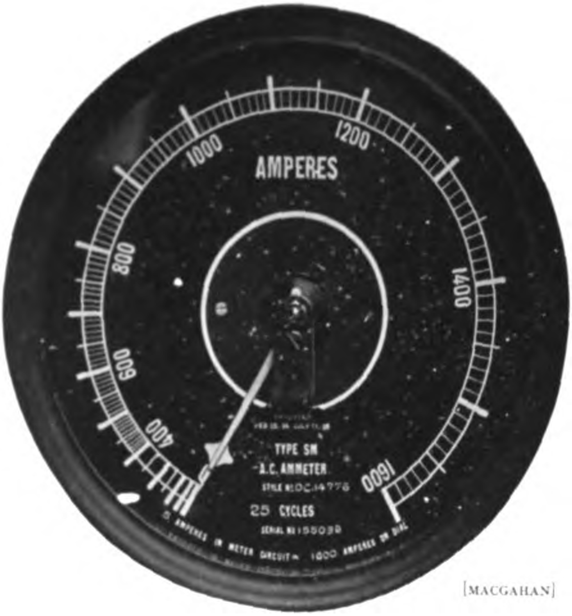

2-FT.
THREE 9 IN. ROUND TYPE METERS
1-FT.
THREE 9 IN. ROUND TYPE METERS
1-FT. 4 IN.
THREE 7 IN. ROUND TYPE METERS
1-FT.
THREE 7 IN. ROUND TYPE METERS
1-FT. 8 IN.
THREE VERTICAL EDGEWISE METERS (WIDE TYPE)
1-FT. 4 IN.
THREE VERTICAL EDGEWISE METERS (NARROW TYPE)
1-FT. 8 IN.
THREE HORIZONTAL EDGEWISE METERS
1-FT.
THREE HORIZONTAL EDGEWISE METERS
2-FT. 8 IN.
SIX 9 IN. ROUND TYPE METERS
2-FT.
SIX 7 IN. ROUND TYPE METERS
1-FT. 4 IN.
SIX 7 IN ROUND TYPE METERS
1 FT. 8 IN.
SIX VERTICAL EDGEWISE METERS (WIDE TYPE)
3-FT. 4 IN.
SIX VERTICAL EDGEWISE METERS (WIDE TYPE)
2-FT. 8 IN.
SIX VERTICAL EDGEWISE METERS (NARROW TYPE)
2-FT. 8 IN.
SIX HORIZONTAL EDGEWISE METERS

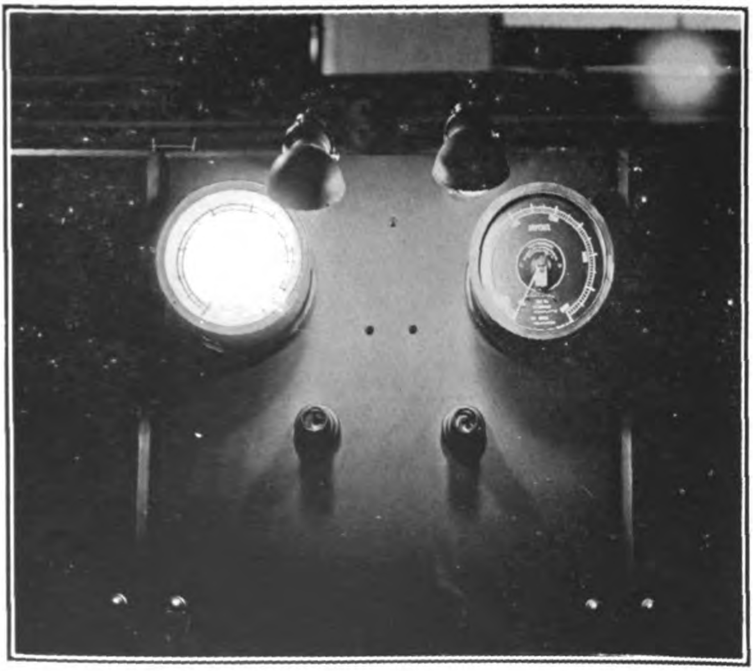
Fig. 1.—Diagram Showing Comparative Areas Required by Various Types of Meters on Switchboard Panels.

The principal types of switchboard indicating meters are given in Table I, the area occupied on the marble by the circumscribing rectangle being tabulated compared to the scale length. To facilitate comparisons a schematic layout of various panels



[MACGAHAN]

FIG. 2.—BLACK DIAL METER.



[MACGAHAN]

FIG. 3.—BLACK AND WHITE DIALS COMPARED.

is shown in Fig. 1, using 7-in. and 9-in. round pattern, and edgewise meters. The limitations of round type 7 in. meters have heretofore been short scale length, and the fact that complete lines including wattmeters, frequency, power factor meters, and synchroscopes, as well as d-c. and a-c. ammeters and voltmeters have not been available. The induction principle applied to the 7-in. ammeter, voltmeter and wattmeter has apparently placed this 7-in. construction on an entirely new basis, the scale length being equal or greater than in any previously designed 9-in. meter.

TABLE I

COMPARISON OF SCALE LENGTHS AND SURFACE COVERED

Type of meter	Area marble	Scale length
Round pattern 7½ in. diameter	58 sq. in.	5 to 14½ in. according to make
" " 9½ in. " *	110 " "	6½ to 14½ in. " " "
Horizontal edgewise 6 x 8½ in.	51 " "	6 in.
Vertical " 4 x 18 in.	54 " "	12 in.
" " 4 x 18 in.	72 " "	12 in.
" " 5½ x 15½ in.	82 " "	12 in.

*Front connected, space including that taken by terminals.

TABLE II

COMPARISON OF AREA ON PANEL REQUIRED PER SQUARE INCH OF SCALE

Type of meter	Square inch area of panel required per inch length of scale
7½ in. round pattern (average)	11
7½ " " " (induction type)	3.9
9½ " " " " "	7.5
9½ " " " (average)	15
6 x 8½ in. horizontal edgewise	8.8
4 x 18 in. vertical "	6
5½ x 15½ in. vertical "	6.8
Illuminated dial (average)	16

READABILITY

Under this heading we may consider scale length and distribution, form of scale, reflections from glass and illumination. In a true comparison it should be noted that if the long scale takes a larger case the distance from the operator is increased by a less compact arrangement of panels. A basis for comparison is the ratio of area of circumscribing rectangle to the scale length in inches. Table II shows such a comparison.

In voltmeters, readability at the normal point should be high; in ammeters, readability should be a maximum at the high points of the scale, as overloads should be indicated with the greatest accuracy. Table III gives a comparison of the inches per volt, on the scale, at the 115-volt point, in various types of 150-volt scale voltmeters.

A consideration of importance as affecting readability is that of the proper scale and pointer illumination. The tendency is now to limit the so-called " illuminated dial " meters to switchboards of a highly decorative character, and to heavy capacity d-c. panels whose size is determined by the other apparatus mounted on them. Moreover, rear illumination is not of much value in an operating room in which the general illumination has been worked out upon proper lines. Full glass front plates instead of metal covers with curved slots in them for showing the scales, greatly improve the readability by thoroughly illuminating the dial and by allowing the whole length of the pointer to be seen instead of showing only an " index " through a slot. By proper arrangement of the illumination, troublesome reflections from flat glass fronts can be entirely eliminated and readings can be taken accurately from any angle, a matter of much greater difficulty in the case of the curved glass used in edgewise meters.

TABLE III
COMPARISON OF VOLTMETER POINTER DEFLECTIONS

Rating	Size	Type	Point	Inches per volt
150-volt	7⅜ in.	Round pattern (induction type) a-c.	115-volt	0.16
" "	7⅜ in.	" " (average) a-c.	" "	0.035
" "	9⅜ in.	" " (induction type) a-c.	" "	0.16
" "	9⅜ in.	" " (average) a-c.	" "	0.05
" "	9¼ in.	" " (D'Arsonval type) d-c.	" "	0.052
" "	6 x 8½ in.	Horizontal edgewise a-c.	" "	0.023
" "	4 x 18 in.	Vertical edgewise a-c.	" "	0.13

Fig. 2 shows a novel arrangement of a black dial with white figures and pointer which in certain instances will be found advantageous. A white mark on a black ground is much easier to see than a black mark on white. A white object causes a certain amount of " halation " in the eye or through a photographic lens, causing the mark to look larger. This halation thus tends to blur black lines on white dials. The eye automatically tends to adjust itself to this, causing a certain amount of strain.

As a lens cannot adjust itself to such varying conditions, a photograph of a white dial alongside of a black dial meter under identical conditions of illumination will show the real difference in readability. The photograph reproduced in Fig. 3 was taken with every possible precaution to insure an exact comparison, and the result is in favor of the black meter. Meters thus arranged with black dials have been used very successfully on electric locomotives operating often at night or in tunnels, where the glare from a white dial would seriously interfere with the driver's view of the track ahead or the signals.

THEORY AND PERFORMANCE OF INDUCTION INSTRUMENTS

The ammeters, voltmeters and wattmeters with which the writer is most familiar consist of a movement comprising an aluminum drum rotating in the air gap of an electromagnet, through the coils of which pass the currents to be measured, in the manner generally known as the "induction type" construction. Such instruments may be said to differ from the moving coil electromagnetic instruments in that the currents in the movable element which react upon the field of the stationary element, thus producing torque, are induced in the moving element by the transformer action of the primary coil and core, instead of being conducted into it by means of flexible spring-conductors.

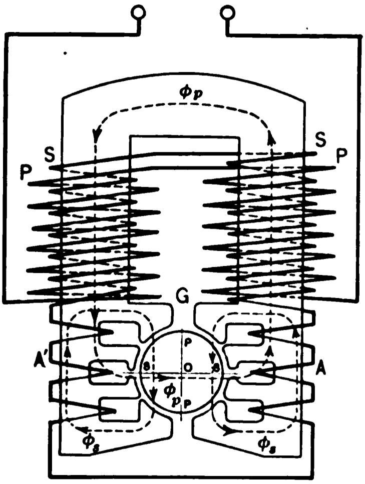


FIG. 6.—DIAGRAM OF AMMETER ELECTROMAGNET.

In analyzing the action of this instrument it is clearer to consider it in the light of an ordinary moving coil electromagnetic instrument than as an induction motor, although it is in reality a special form of induction motor.

Thus in Fig. 6 the laminated iron circuit of an ammeter is shown, with its annular air gap in which the aluminum drum is free to rotate. *P* represents a primary winding through which passes the current to be measured. *S* - *S* is a secondary winding short circuited on itself. The dotted lines marked ϕ represent the various magnetic fluxes produced by currents in the coils.

The windings P and S are the same in relation to each other as the primary and secondary windings of a current transformer, and their currents are similarly related. Thus the functioning of this type of induction ammeter can be said to be due to a combination of the actions in a current transformer and an induction motor. In this respect it differs from all previous types of induction meters, the result being an exceptional freedom from frequency and temperature errors, as explained further.

Fig. 4 shows the movement of such a meter, and Fig. 5 shows the electromagnet assembled on the base.

Considering the induction type ammeter from the moving coil meter standpoint, we have,

$$\text{Torque} = \phi\, I \cos \gamma\, k \qquad (1)$$

in which

ϕ = flux produced by stationary coil, passing through the moving coil.

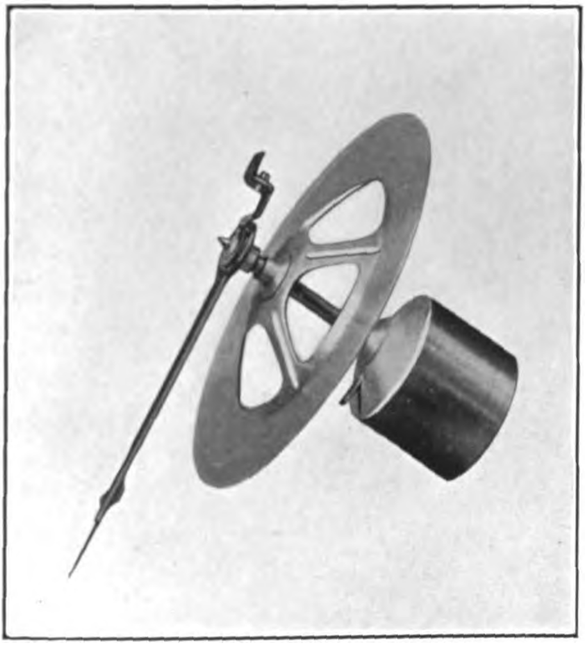
I = current, moving coil

γ = angle of lag.

k = constant.

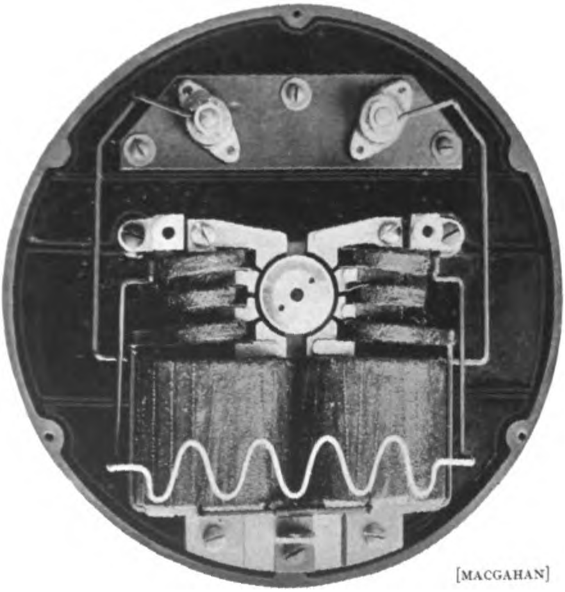
In the induction meter, I in drum I_D is equal to $\frac{\text{voltage in drum,}}{\text{impedance of drum}}$ or proportional to $\frac{\phi N}{Z_D}$, (N = frequency. Z_D = impedance of drum.)] If ϕ were oscillatory, such as due to single-phase currents in primary coil P only, the secondary currents induced in the drum would be in the plane $O\,P$ only, and thus would not be in a position to cause rotary torque in connection with the primary flux ϕ_p.

If, however, an additional flux, differing in phase, is introduced by means of additional coils S, this flux ϕ_s will in the instrument as constructed be in a direction at right angles to ϕ_p, and will thus cause torque by reacting upon the secondary currents in the drum which flow in the direction $O\,P$. At the same time the flux ϕ_s will cause secondary currents in the drum in the direction $O\,S$, which are in a position to react upon ϕ_p to produce torque. Any secondary currents induced in the drum in intermediate directions may be resolved into components in directions $O\,P$ or $O\,S$ and thus are represented by currents in these directions only. It is understood that the fluxes ϕ_p and ϕ_s do not actually exist separately, but act in combination to produce a resultant flux ϕ_r which rotates with a frequency equal to that of the circuit. They may be treated separately for purposes



[MACGAHAN]

FIG. 4.—MOVEMENT OF INDUCTION TYPE AMMETER.



[MACGAHAN]

FIG. 5.—ELECTROMAGNET ASSEMBLED ON BASE.

of analysis, however. Thus the law of torque of such an instrument can be written:

$$\begin{aligned} \text{Torque} &= \phi_p \, I_s \cos\alpha + \phi_s I_p \cos\beta \qquad (2) \\ \alpha &= \text{angle between } \phi_p \text{ and } I_s \\ \beta &= \text{`` \quad ``} \quad \phi_s \text{ and } I_p \end{aligned}$$

It is assumed throughout this discussion that the values I_p, I_s, I', I'', etc., for currents are stated in terms of equal turns, or as "ampere-turns."

In order to produce currents in the coils *S*, differing in phase from those in the primary coils *P*, and thus produce the fluxes ϕ_s and ϕ_p, the "transformer" arrangement of coils is used in the ammeter. The coils *P* are wound directly over secondary coils, which are in turn short-circuited through the distributed pole-piece coils *S*. The relations between the currents and fluxes are the same as those in current transformers, shown graphically in Fig. 7, where I' = current in primary, I'' = secondary current, and I_m = magnetizing current.

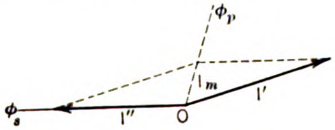


FIG. 7.—DIAGRAM OF TRANSFORMER RELATIONS.

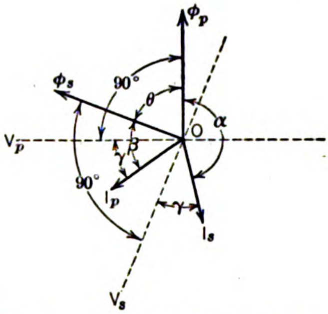


FIG. 8.—VECTOR DIAGRAM OF METER RELATIONS.

The flux due to the magnetizing component of the primary coil is in the direction $O\,\phi_p$. The flux produced by the current in the secondary coils is in the direction $O\,\phi_s$, in phase with the current I'' in the secondary and pole-piece windings. It is seen that the phase angle between the fluxes ϕ_s and ϕ_p is roughly speaking 90 deg., thus producing a rotation of the moving element as previously explained.

The ϕ_p, as in a current transformer, is inversely proportional to the frequency, but ϕ_s is independent of the frequency, being only proportional to I''.

In the vector diagram Fig. 8, let $O\,\phi_p$ = the primary and $O\,\phi_s$ the secondary flux. At right angles to each are the voltages $O\,V_p$ and $O\,V_s$ induced by these fluxes in the moving drum. Lagging behind these voltages are components of the current in the drum, $O I_p$, due to ϕ_p, and $O I_s$ due to ϕ_s. (See equation **2**).

Let θ = angle between ϕ_p and ϕ_s.
γ = lag of currents in drum behind V_p and V_s.
Then we have $\alpha = \gamma + \theta + 90$ deg.
$\beta = \gamma - \theta + 90$ deg.

Whence, $\cos\alpha = \sin(\gamma + \theta)$ and $\cos\beta = \sin(\gamma - \theta)$

Substituting in (**2**),

$$\text{Torque} = \phi_p I_s \sin(\gamma + \theta) + \phi_s I_p \sin(\gamma - \theta) \tag{3}$$

The currents in the drum being proportional to the voltage induced in it divided by the impedance of the drum circuit we have.

$$I_s = \frac{N \phi_s K'}{Z_D K''} \tag{4}$$

$$I_p = \frac{N \phi_p K'''}{Z_D K''} \tag{5}$$

in which K', K'', K''', are constants which will hereafter be omitted for clearness.

As $\phi_p = \dfrac{I'}{N}$ and $\phi_s = I'$, I' being the current in the primary coil, we obtain by substitution

$$I_s = \frac{N I'}{Z_D} \tag{6}$$

$$I_p = \frac{I'}{Z_D} \tag{7}$$

Substituting in (**3**)

$$\text{Torque} = \frac{(I')^2}{Z_D} [\sin(\gamma + \theta) + \sin(\gamma - \theta)]; \text{ whence,}$$

$$\text{Torque} = \frac{(I')^2}{Z_D} (\cos\gamma \sin\theta) \tag{8}$$

It is evident that Z_D, γ, and θ are functions varying with the frequency and therefore in order to make the meter independent of frequency we must make $\cos\gamma \sin\theta = Z_D$; that is, the function $\cos\gamma \sin\theta$ must vary as the impedance of the drum.

This condition for independence from frequency variations can in reality be only approximated. The actual design is necessarily the result of extended experimentation and laboratory work, combined with calculation, so as to secure the greatest possible range over which the meter will be independent of frequency. The performance curves on the ammeters in question show a maximum difference in readings for any two frequencies between 25 and 60 cycles of ½ per cent. (See Fig. 9).

In the case of the voltmeter, the primary coil is wound with fine instead of coarse wire, and an external series non-inductive resistor is used, wound with wire having a zero temperature coefficient.

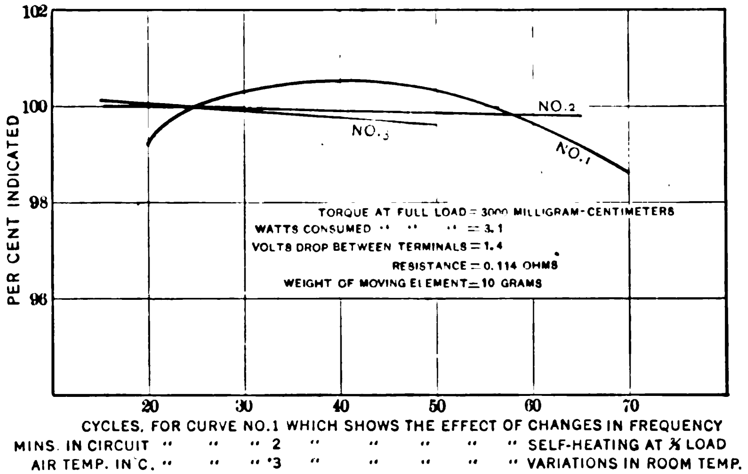


FIG. 9.—PERFORMANCE CURVES, AMMETER.

The proportion of series ohmic resistance to the total impedance is made very high and the current in the primary coils of the voltmeter is almost independent of the frequency, thus approximating the results found in the ammeter. (See Fig. 10.)

In the above discussion, only the effect of the variation of frequency upon the torque was covered. In addition an error may be introduced by the varying temperature, changing the resistance of the drum and thus the currents I_p and I_s induced in the drum (see equation **3**). In order to correct for this variation, the secondary coil circuit is arranged to have a temperature coefficient of resistance such as to exactly cancel the effect of increased resistance of the drum. To do this advantage is again taken of the effects taking place in current transformers.

If in a current transformer the primary current be kept constant, the secondary current will remain approximately constant for a considerable variation in secondary resistance. Thus any increase in secondary resistance causes a proportional increase of the flux in the core.

In the particular induction ammeter construction described, the secondary circuit is wound partly with copper and partly with wire of low temperature coefficient, the resulting temperature coefficient of the circuit being such as to increase the fluxes in the iron when the temperature of the aluminum drum rises.

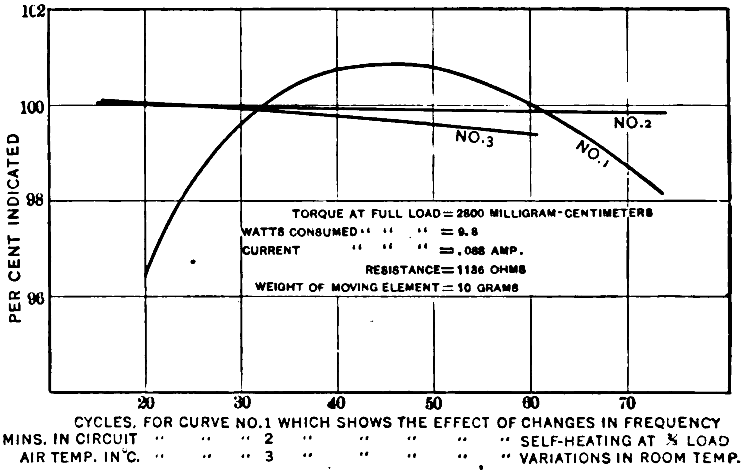


FIG. 10.—PERFORMANCE CURVES, VOLTMETER.

By a proper proportioning of temperature coefficient of the secondary winding the temperature compensation is effected with great exactness.

The equations (**4**) and (**5**) show the effect of a variation of temperature and consequently Z_D upon the induced currents in the drum.

From equation (**3**) by substituting (**4**) and (**5**) and omitting constants we have.

$$\text{Torque} = \frac{\phi_p N \phi_s}{Z_D} \sin(\gamma + \theta) + \frac{\phi_s N \phi_p}{Z_D} \sin(\gamma - \theta)$$

$$= \frac{N \phi_p \phi_s}{Z_D} (\cos \gamma \sin \theta)$$

From this we see that the condition for zero temperature error of meter is that

$$\phi_p \, \phi_s = Z_D \text{ (considering the frequency as constant)}$$

As ϕ_s is virtually independent of the resistance and thus of temperature, we may for simplicity write this condition,

$$\phi_p = Z_D$$

At a fixed current, ϕ_p is a function only of the impedance of the secondary coil circuit. From this it is evident that the temperature coefficient of the secondary winding must be the same as that of the drum, in order to make the temperature error of the meter zero.

In actual practise, there are a number of factors tending to complicate the above relations, such as the temperature variations of the iron and of the control spring, etc., so that the proper proportions of copper wire to resistance wire in the secondary circuit can best be determined experimentally. The actual temperature errors are shown in Figs. 9 and 10.

It will be noted that the results as to temperature coefficient and as to frequency errors compare very favorably with those in meters operating on the moving iron or moving coil principles.

A similar arrangement for temperature and frequency compensation has been worked out in the wattmeter.

A paper to be presented at the 29th *Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June* 28, 1912.

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COMPENSATING WATTMETERS

BY A. L. ELLIS

In these days of large units and stupendous engineering undertakings one is apt to overlook the problems involved in assigning to little things an accurate valuation.

The output of a very large generator can be determined within 1 per cent by means of instruments easily obtainable, if not already at hand; yet assigning a value to the energy delivered to a small metal filament lamp or the potential circuit of an induction meter presents some difficulties not readily overcome. This is chiefly due to the low watt consumption which gives a very small deflection on the scale of wattmeters designed for other than laboratory use.

There are a number of cases where a suitable indicating wattmeter is greatly needed, as for instance, in measuring the core-loss of small transformers, bell ringing transformers, compensators for metal filament lamps, small fan motors, small three-phase motors running light, shunt losses in induction meters, etc. It is generally desirable to make such measurements when a given e.m.f. is applied to the terminals of the devices. As low capacity wattmeters are produced by increased turns in the coil in series with the load it is also desirable to connect the voltmeter and the " potential terminals " of the wattmeter across the load itself, in order to avoid the phase displacement and $C R$ drop which occurs in the wattmeter current coils.

This arrangement has the disadvantage that the potential circuit losses of both the voltmeter and wattmeter are then included in the watts indicated by the latter instrument, thus making it necessary to apply corrections to the readings. It frequently happens that the instrument losses are many times greater than the loss to be determined, hence the result obtained is the difference between two nearly equal quantities. This together with small scale deflection makes accurate determinations practically impossible.

An instrument for this work should possess the following characteristics distinguishing it from the ordinary low reading wattmeter.

1. It should be so designed that its errors can be readily computed for all conditions of load, power factor of load, scale position, etc., and readings corrected for these errors.
2. Its indications should be compensated for its own losses.
3. Its indication should be compensated for loss in the voltmeter or other instruments which may be connected across the terminals of the device being measured.
4. It should have a large current capacity in terms of its full scale watt value, as a great many of the small energy consumers operate at low power factors.
5. It should possess high torque in order that its life of unimpaired accuracy may not be shortened.
6. Its moving system should be damped.
7. It should be shielded to protect it from stray magnetic and electrostatic fields.

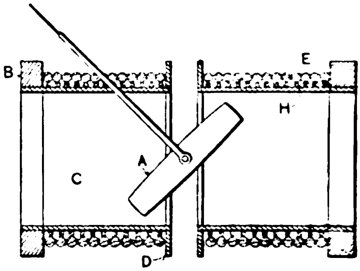

Fig. 1.

Fig. 1 shows diagrammatically the compensated wattmeter as commonly constructed.

The moving coil *A* is pivoted between two similar spools upon which are wound the series or current coil *E* and the compensating coil *H*.

The spool comprises the brass supporting casting *B*, into which is soldered a brass tubing *C*, having a flange *D* to form a channel for winding. The spool is split radially by one saw-cut to reduce error due to eddy currents.

The turns of the series coil *E* should be concentrated about the moving coil in the most effective position, the available space should be filled with copper, and as little insulation used as will insure freedom from short circuits. Some of the available space must be given up to the compensating coil; hence it is usually composed of fine wire, 0.005 to 0.010 in. (0.125 to 0.254 mm.).

In Fig. 1 the compensating coil *H* has approximately the same number of turns as series coil *E* and is wound beneath because, being fine wire, it is best supported when wound directly upon the metal spool.

Sometimes the compensating coil is wound upon the series coil either directly or on a separate support. In either case, the adjustment of the compensating coil is obtained by adding or subtracting turns, until no deflection is obtained when the current for the moving coil is taken through the series and compensating coils connected in series and opposing.

Since the coils *E* and *H* have not the same radius they will not affect the moving coil equally for all scale positions; consequently the compensation can be made exact for one scale position only. This is also true for more than one layer and the error becomes more pronounced as the layers increase, or if the compensating circuit is wound outside of the series coil, either directly or as a separate coil.

When constructed as in Fig. 1, an average in equality of 4.5 per cent and a maximum of 6 per cent has been observed for the different scale positions.

True compensation for all scale positions can only be obtained by using a concentric cable when winding the series coil, the wire of the compensating coil forming the core upon which the strands of the series coil cable are laid up. Such an instrument possessing a 150-watt scale has been made.

There are, however, structural difficulties which preclude the general use of this method, namely: (1) the problem of bringing out the compensating core and securing same so that it will not break off at the point where it enters the finished coil; (2) the difficulty of securing sufficiently high insulation between core and cable to permit the use of the instrument upon 150-volt circuits; (3) the fact that, because where small conductors are concerned cable construction greatly reduces the amount of copper that can be wound in a given space because this is still further reduced by the compensating core, the current is so limited that the instrument is suitable for measurements around 100 per cent power factor only.

Very good results have been obtained by winding the series coil in several layers and at the same time winding one or more fine compensating wires so distributed that their respective magnetic effects in relation to the moving coil are substantially equal.

Fig. 2 gives the departure from the compensation for various scale positions. The curves are plotted from observations, using a wattmeter like that in Fig. 1, and one having specially wound coils.

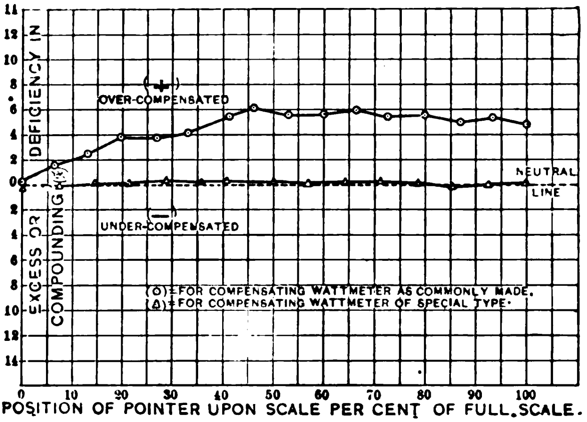

FIG. 2.—CURVES SHOWING COMPOUNDING BETWEEN CURRENT AND COMPENSATING WINDINGS

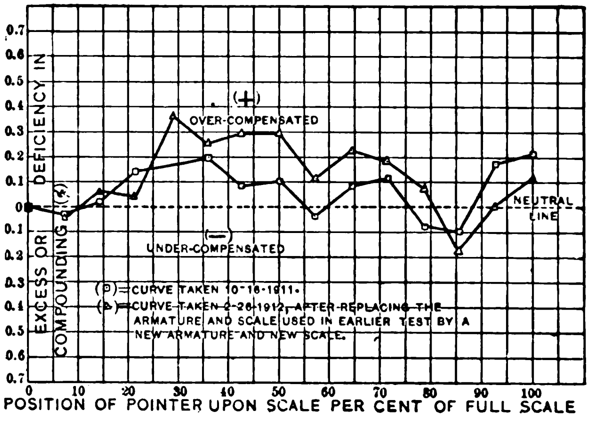

FIG. 3.—COMPOUNDING BETWEEN CURRENT COILS AND COMPENSATING WINDING IN WATTMETER OF SPECIAL TYPE.

Curves drawn to twenty times the scale of those in Fig. 2.

Fig. 3 is interesting, as it shows the accuracy to which the actual compensation was observed. The curves are for the specially wound wattmeter of Fig. 2 and are plotted to a scale twenty times larger. The second set of observations was taken four months later than the first, during which time the moving coil had been replaced by a new one and a new scale marked for it. The greatest difference between observed points on the two curves does not exceed 0.2 per cent of the compensation, showing that between 0 and 25 per cent of full scale the compensation is correct within 0.2 per cent and, excepting one observed point, within 0.3 per cent for the remainder of the scale.

Equally good results can be obtained with a second fine wire wound in the series coil, which may be used to feed a voltmeter or other device and automatically subtract from the wattmeter indication the energy so delivered. The connections in this case are shown in Fig. 4, which is self-explanatory.

Table I gives the percentage difference in the watts observed when measuring a given load first " direct " and then compensating; the number of watts obtained when used direct is taken as standard. This shows much better compensation in the case of the special type under all conditions.

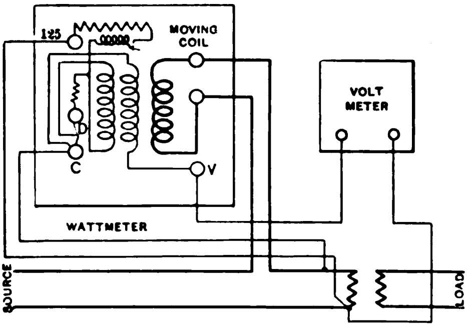

FIG. 4

The " computed variation " at the bottom of the table is the difference in per cent one would expect to observe, based upon the potential circuit losses and the departure from exact compensation, neglecting the effect of mutual induction.

While the wattmeter can be closely compensated for the voltmeter losses, the voltmeter indications must be corrected for the added ohmic resistance and the disturbance due to mutual inductance between series and compensating coils; the resultant self-inductance of these coils is equal to zero.

Fig. 5 gives the e.m.f. due to mutual induction at 60 cycles for two capacities of wattmeters, showing how this e.m.f. varies with the current taken by the load.

Fig. 6 gives the error in the indication of the voltmeter in volts at 60 cycles for all load power factors, when the particular wattmeter considered is loaded with its maximum rated current (2.25 amperes), and operated upon circuits of 100 volts or over with either lagging or leading current. It is to be noted that the error is roughly constant for all low power factors up to 50 per cent power factor, the total variation amounting to 0.2 volt. Beyond 80 per cent power factor the error falls rapidly to zero. If the ratio $\frac{\text{mutual e.m.f.}}{\text{line e.m.f.}}$ is less than 2 per cent, the indication expressed in volts is approximately equal to the mutual e.m.f. $\times \sin \theta$, where θ is the phase angle of the load. The effect

TABLE I.—TEST OF COMPENSATING WATTMETERS
THE OBSERVED VARIATION IN CALIBRATION WHEN SHIFTING FROM DIRECT TO COMPENSATING

(Variation given in terms of the " direct " calibration taken as standard.)

Watts read on test instrument	On unity power factor			On power factor = 0.1		
	Wattmeter No. 1 common type (Per cent)	Wattmeter No. 2 (Special type)		Wattmeter No. 1 common type (Per cent)	Wattmeter No. 2 (Special type)	
		Alone (Per cent)	With voltmeter (Per cent)		Alone (Per cent)	With voltmeter (Per cent)
60 Cycles per Second; Current Lagging						
25.0	−1.25	−0.16	−0.27	−0.88	+0.15	+0.02
20.0	−0.71	−0.07	−0.17	−0.87	+0.11	−0.11
15.0	−1.12	−0.09	−0.30	−0.95	+0.05	+0.01
10.0	−0.90	−0.25	−0.26	−0.75	+0.16	+0.18
125 Cycles per Second; Current Lagging						
25.0	−1.03	−0.07	+0.07	−0.30	−0.07	−0.19
20.0	−0.73	+0.03	−0.05	−0.39	+0.09	+0.15
15.0	−1.01	−0.19	−0.34	−0.70	+0.49	+0.28
10.0	−0.50	−0.06	−0.06	−1.18	+0.41	+0.26
125 Cycles per Second; Current Leading						
25.0	−0.66	−0.14	−0.22	−0.56	+0.29	+0.33
20.0	−0.64	−0.08	−0.31	−0.48	−0.20	−0.17
15.0	−1.31	−0.46	−0.41	−1.05	−0.10	−0.21
10.0	−1.13	−0.12	−0.12	−0.89	−0.11	−0.16
Computed Variation or Error (Based upon potential Losses and per cents on Fig. 2.)						
25.0	−0.59	−0.07				
20.0	−0.70	−0.10				
15.0	−0.68	−0.02				
10.0	−0.83	−0.03				

NOTE: The theoretically perfect wattmeter should show no variation; neglecting mutual induction.

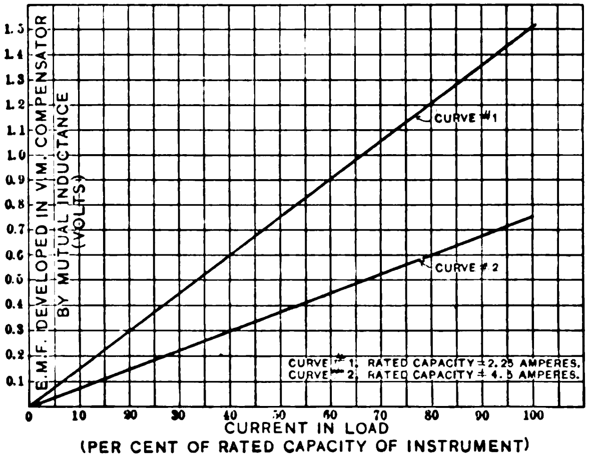

Fig. 5.—Curves giving the E. M. F. Induced in Voltmeter Compensator by Mutual Inductance.

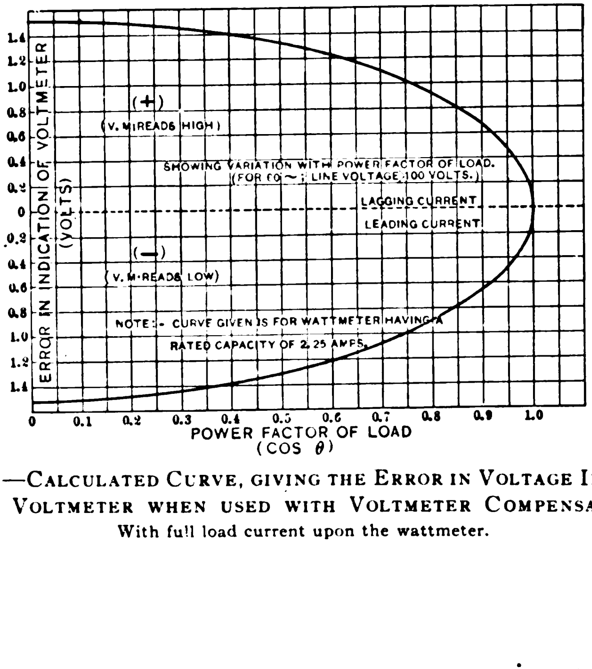

Fig. 6.—Calculated Curve, giving the Error in Voltage Indicated by Voltmeter when used with Voltmeter Compensator.

With full load current upon the wattmeter.

of added resistance on the voltmeter indication is easily computed to any accuracy required.

The mutual inductance due to the compensating coil causes no appreciable error in the wattmeter at any load or any power factor. The reason may perhaps be better understood by referring to the vector diagram shown in Fig. 7 which, while not completely representing all that takes place in the operation of the wattmeter, shows the principal reason why the indication is not affected. In this diagram

I_T = phase of true load current.

E_m = phase of the e.m.f. induced by mutual inductance which leads I_T by 90 deg. in time phase (considering that compensating winding is reversed).

E_T = phase of true load potential.

θ = true angle between phases of I_T and E_T.

E_i = the total effective volts impressed upon the potential circuit = resultant of E_T and E_m.

Read E' for lagging and E'' for leading current.

It will be seen at a glance that, since a line can be drawn perpendicular to I_T and common to the vectors of the true load and the resultant instrument potentials, and since the distance of this line from the origin along I_T represents that component of the potentials in phase with I_T, or in other words determines the watts, whatever the value assigned E_m, the wattmeter indication will not be affected for any given relation between E_T, I_T and θ.

This is not strictly true when all factors are considered. The diagram considers only the e.m.f.'s due to mutual induction, and neglects the effect of the moving coil, as also the current flow, into the load and into the source, due to E_m. These disturbances are very slight; their combined effects do not produce an observed error. This is fortunate, as it would be difficult to correct for the current flow into the load and source, because, while the constants of the load can be measured, the constants for the source would be difficult to determine and are ever changing.

The common type of wattmeter designed for use on voltages around 110 has a maximum capacity of 150 watts; the ampere capacity is limited to 1.5, in some cases as high as 2 amperes. An instrument of this type, upon low power factors, does not produce a deflection such that the distance of the pointer from zero can be determined very accurately. The capacity of 150 volts is of little value, since the devices to be measured have been designed to operate upon commercial circuits; hence the voltage most frequently used is 110, with probable maximum of 120 volts. On this basis the full scale deflection would be obtained at 62 per cent power factor.

The sensibility of the instrument and its field of usefulness can be enhanced by so proportioning the potential circuit that it will be limited to potentials of 125 volts or less. The series or current coil should be rated as high as possible and the activity of the moving coil increased by increasing the ratio of the inductance to the resistance.

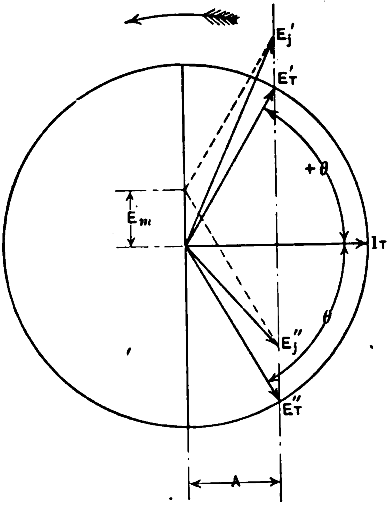

Fig. 7

The special wattmeter previously and subsequently referred to has an ampere capacity of 2.25 amperes, a potential limit of 125 volts and a full scale of 70 watts. On the basis of 120 volts the full scale deflection would be obtained at 26 per cent power factor as compared with 62 per cent power factor for the common type. Deflections around ⅓ scale can be obtained at power factors below 10 per cent within the rated capacity. If left continuously in circuit at rated load a small correction will be necessary, due to the heating effect, but no noticeable disturbance is produced if left in circuit for five minutes at a time with short intervals of rest.

In the design of an instrument metal affords the most certain readily obtainable, and eminently satisfactory mechanical means of definitely locating the various vital parts with respect to one another; yet, when utilized as found in the common type of wattmeter (illustrated in Fig. 1) it becomes a serious source of error due to eddy currents.

The error is greatest at low power factor, because the eddy currents are then nearly in phase with the current through the moving coil, the deflection of the instrument is small and the current producing eddy currents is large.

The magnitude of the error varies with the frequency, power factor, amperes of load, voltage across instrument terminals, and position of pointer on scale, making it practically impossible to correct readings for errors of this nature. The effect of this error is to cause the indications of the instrument to be too small or too large when the load current lags behind or leads the impressed e.m.f.

A comparatively large amount of metal can be used to secure mechanical stability and be so placed with respect to the stationary and moving coils and practically no error results due to eddy currents, even when the sensibility is greatly increased as in the case of the "special" wattmeter.

The "special" wattmeter, besides having robust metal supporting frames, was equipped with magnetically damped moving system and massive iron magnetic shields. Table II gives a comparison between the calculated errors and the observed total accumulation errors at 10 per cent power factor, for 60-cycle lagging current and 125-cycle lagging and leading current, for both the common and special type wattmeter when used direct (as an ordinary wattmeter) and when used compensating. The calculated errors as given take nothing into account except the phase displacement caused by the self-inductance of the potential circuit—the theoretical effects which mutual inductance might produce being completely disregarded.

Referring to the errors observed in the common type of wattmeter, the effects of eddy currents are plainly in evidence. Where it would be expected that the instrument should read high due to the phase displacement of the moving coil circuit, the instrument actually reads low due to eddy currents. This is true whether used compensating or direct; the lack of correct compensation amplifies the error on lagging current and reduces the error on leading current. The magnitude of the error varies with the scale position, being more pronounced when the compensating coil is used, except on leading current, where the variations in the errors due to the different positions tend to neutralize one another. A useful correction factor cannot be supplied with wattmeters of the common type because where we would expect it to read 0.53 per cent high it actually reads anywhere between 0.77 per cent and 2.15 per cent low.

TABLE II. TEST OF COMPENSATING WATTMETERS
THE TOTAL ACCUMULATIVE ERRORS OBSERVED ON POWER FACTOR LOADS

(Figures in table are corrected for scale errors.)

Watts read on test instrument	Power factor of load = 0.1				
	Used direct		Used compensating		
	Wattmeter No. 1 Common type (Per cent)	Wattmeter No. 2 Special type (Per cent)	Wattmeter No. 1 Common type (Per cent)	Wattmeter No. 2 Special type	
				Alone (Per cent)	With voltmeter (Per cent)
	60 Cycles per Second; Current Lagging				
25.0	—0.92	+1.54	—1.85	+1.68	+1.62
20.0	—0.77	+1.55	—1.82	+1.41	+1.30
15.0	—1.10	+1.48	—2.15	+1.54	+1.60
10.0	—1.15	+1.67	—1.51	+1.56	+1.58
*Calculated errors	+0.53	+1.69	+0.53	+1.69	+1.69
	125 Cycles per Second; Current Lagging				
25.0	—1.18	+4.70	—1.21	+4.63	+4.55
20.0	—1.02	+4.32	—1.29	+4.33	+4.47
15.0	—2.05	+3.47	—2.42	+4.09	+3.88
10.0	—2.00	+3.91	—3.14	+4.33	+4.18
*Calculated errors	+1.12	+3.63	+1.12	+3.63	+3.63
	125 Cycles per Second; Current Leading				
25.0	+1.63	—2.94	+1.01	—2.62	—2 58
20.0	+1.58	—2.95	+1.09	—3.16	—3.34
15.0	+1.42				
10.0	+1.68	—2.67	+1.02	—2.78	—2.83
*Calculated errors	—1.12	—3.63	—1.12	—3.63	—3.63

*The calculated errors take nothing into account except the self-inductance of potential circuit.

The wattmeter having special coils shows no observable error due to eddy currents, the calculated error and observed error have substantially the same magnitude and sign, while the error for the various scale positions is practically the same. The excellence of the compensation is to be noted in the good agreement between the errors when used direct and compensating, and even when compensating for a voltmeter in addition. A correction factor can be applied with advantage to the readings of this instrument, namely the phase angle of the potential circuit.

The correction factor is large, compared with that calculated for the common type, because in providing the large volt-ampere capacity the torque was kept up at the expense of the small time constant of the potential circuit rather than increase the impedance of the series coil, as doing the latter would be likely to disturb the condition of the circuit upon the introduction of the wattmeter. This would be undesirable, for it is a prime requisite, as pointed out in the beginning that the design be such that its errors can be readily computed for all conditions of load, etc., to be useful as a wattmeter on low power factors.

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POTENTIAL TRANSFORMER TESTING

NOTE ON THE EFFECT OF THE RESISTANCE OF THE DETECTOR CIRCUIT, IN DETERMINING THE RATIO OF TWO ALTERNATING VOLTAGES, AND THE PHASE ANGLE BETWEEN THEM, BY THE BALANCE METHOD

BY J. R. CRAIGHEAD

In the use of the balance method of determining the ratio of the primary and secondary voltages of potential transformers, certain variations in the result were noted which appeared to be dependent on the relation of the resistance of the detector (R_D in Fig. 1) to the balance resistance R_1 and R_2. A short theoretical investigation and a few tests were made to determine the cause and the order of magnitude of the errors involved, and to ascertain safe limits of operation. As the measurement of the detector voltage has frequently been suggested as a means of determining phase angle between voltages, the relation of the detector resistance to this measurement was also considered.

The cause of error is the current drawn in the detector circuit. If the two voltages to be compared are in phase and of the same wave form, no current flows in the detector circuit when a balance is obtained, and no error can result from this cause. In the usual condition, however, as in determining the voltage ratio and phase angle of a potential transformer, the voltages are slightly out of phase and may even differ slightly in wave form. Then the balance is obtained when the detector indicates minimum or zero but a current flows in the detector circuit proportional to the voltage across the detector (practically in quadrature with the voltages compared) and inversely proportional to the resistance of the detector circuit. This current evidently passes through one section of the bridging resistance placed across the greater voltage, but not through the other. Since the balance will be obtained when the voltages across the two resistances reach a certain relation, and since the currents in these resistances are unlike, the ratio of resistances is in general not an exact representation of the ratio of the voltages compared; and since the detector current, taken in quadrature from the current in one of the bridging resistances, causes it to differ in phase from the current in the other bridging resistance, the minimum reading of the detector will be representative of an angle (α in Fig. 2) which is not identical with γ, the phase angle between the voltages compared.

The nature of the detector employed has an influence on the result. This may be (*a*) a simple voltmeter (see Figs. 1 and 2)

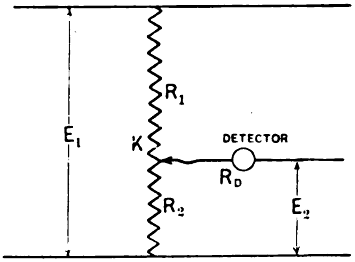

FIG. 1

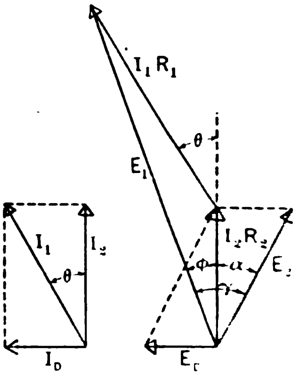

FIG. 2

or (*b*) a dynamometer separately excited. The excitation may be in phase with E_2, E_1, I_2 or I_1. The error with excitation in phase with I_2 is the same as under (*a*). If the excitation is supplied in phase with E_1, E_2 or I_1, the balance is obtained under slightly different phase relations, and the errors enter into the results in slightly different ways.

To obtain an idea of the order of magnitude of the errors involved, it will be sufficient to analyze case (*a*) where the detector is a simple voltmeter, reading a minimum at balance, and where the phase angle may be obtained from this minimum reading.

Referring to Figs. 1 and 2, assume E_1 and E_2 to be two sine wave voltages differing in phase by the angle γ, balanced for comparison as indicated in the sketch. The voltage E_D across the detector is in quadrature with the voltage $I_2 R_2$ across R_2, since the contact point K which marks the division of the total bridging resistance into R_1 and R_2 has been shifted until the reading of the detector is a minimum. If I_1, I_2, and I_D are the currents flowing in the resistances R_1, R_2 and R_D respectively

$$I_2 R_2 = \sqrt{E_2^2 - E_D^2}$$

whence

$$I_2 = \sqrt{\frac{E_2^2 - E_D^2}{R_2^2}}$$

$$I_D = \frac{E_D}{R_D}$$

$$I_1 = \sqrt{I_2^2 + I_D^2} = \sqrt{\frac{E_2^2 - E_D^2}{R_2^2} + \frac{E_D^2}{R_D^2}}$$

The angle between I_1 and I_2, or between $I_1 R_1$ and $I_2 R_2$, is

$$\theta = \cos^{-1}\left(\frac{I_2}{I_1}\right)$$

Now

$$E_1 = \sqrt{I_1^2 R_1^2 + I_2^2 R_2^2 + 2\, I_1 R_1 I_2 R_2 \cos\theta}$$

and for true ratio of voltages

$$\frac{E_1}{E_2} = \frac{\sqrt{I_1^2 R_1^2 + I_2^2 R_2^2 + 2\, I_1 R_1 I_2 R_2 \cos\theta}}{E_2}$$

substituting and simplifying

$$\frac{E_1}{E_2} = \sqrt{\frac{E_2^2 - E_D^2}{E_2^2} + \left(\frac{R_1 + R_2}{R^2}\right)^2 + \left(\frac{E_D R_1}{E_2 R_D}\right)^2} \qquad \textbf{(1)}$$

Equating to $\frac{R_1 + R_2}{R_2}$ and solving for R_D,

$$R_D = \frac{R_1 R_2}{R_1 + R_2} \qquad \textbf{(2)}$$

That is, if the resistance of the detector is adjusted to the value obtained from equation (**2**), the reading obtained from

R_1 and R_2 will accurately represent the ratio of voltages without correction for phase angle, the errors in ratio due directly to phase angle, and those due to the detector current offsetting one another. When R_1 is large compared with R_2, this formula becomes approximately

$$R_D = R_2$$

For instance, in testing a transformer rated 2200 : 110 volts, the values of resistance used were $R_1 = 19{,}000$ ohms and $R_2 =$ 1000 ohms.

$$R_D = \frac{R_1 R_2}{R_1 + R_2} = 950 \text{ ohms.}$$

If R_D is kept at 1000 ohms, the error in ratio determination is negligible, amounting to 0.0006 per cent for $\gamma = 1$ deg., 0.0016 per cent for $\gamma = 2$ deg., and 0.006 per cent for $\gamma = 4$ deg.

The maximum limits to which the error may reach are shown as follows: If α is the angle between E_2 and $I_2 R_2$, equation (**1**) may be rewritten,

$$\frac{E_1}{E_2} = \sqrt{\left(\frac{R_1 + R_2}{R_2}\right)^2 \cos^2 \alpha + \left(\frac{R_1}{R_D}\right)^2 \sin^2 \alpha}$$

$$= \frac{R_1 + R_2}{R_2} \cos \alpha \sqrt{1 + \left(\frac{R_2}{R_D}\right)^2 \left(\frac{R_1}{R_1 + R_2}\right)^2 \tan^2 \alpha}$$

If ϕ is the angle between E_1 and $I_2 R_2$, equalling $\gamma - \alpha$,

$$\cos \phi = \frac{I_2 R_2 + I_1 R_1 \cos \theta}{E_1}$$

$$\text{Since } \cos \theta = \frac{I_2}{I_1} \text{ and } I_2 R_2 = E_2 \cos \alpha$$

$$\cos \phi = \frac{E_2 \cos \alpha + E_2 \cos \alpha \dfrac{R_1}{R_2}}{\dfrac{R_1 + R_2}{R_2} E_2 \cos \alpha \sqrt{1 + \left(\dfrac{R_2}{R_D}\right)^2 \left(\dfrac{R_1}{R_1 + R_2}\right)^2 \tan^2 \alpha}}$$

$$\cos \phi = \frac{1}{\sqrt{1 + \left(\dfrac{R_2}{R_D}\right)^2 \left(\dfrac{R_1}{R_1 + R_2}\right)^2 \tan^2 \alpha}} \qquad (3)$$

whence

$$\frac{E_1}{E_2} = \frac{R_1 + R_2}{R_2} \times \frac{\cos\alpha}{\cos\phi} \qquad (4)$$

Now since $\gamma = \alpha + \phi$,

$\cos\alpha$ varies from 1 to $\cos\gamma$, while
$\cos\phi$ varies from $\cos\gamma$ to 1

at the same time R_2/R_D varies from 0 to infinity.
Hence the correction factor to be applied to the ratio of resistances varies with changes of R_D from $\cos\gamma$ as one limit through unity to $1/\cos\gamma$ as the other. It will evidently be equal to unity (no correction necessary) when $\alpha = \phi = \gamma/2$. In this case, from equation (**3**)

$$\cos\alpha = \cos\phi = \frac{1}{\sqrt{1 + \left(\frac{R_2}{R_D}\right)^2 \left(\frac{R_1}{R_1 + R_2}\right)^2 \tan^2\alpha}}$$

which, solved for R_D, gives

$$R_D = \frac{R_1 R_2}{R_1 + R_2}$$

which is equation (**2**) again. That is, the same value of R_D which gives a correct ratio reading, gives also a phase angle obtainable from the minimum reading of the detector by the formula

$$\alpha = \sin^{-1}\left(\frac{E_D}{E_2}\right)$$

which is one-half of the actual phase angle γ.
This method of obtaining phase angle, however, falls into serious error if the resistance R_D varies more than a few per cent from the theoretical value, and correction is too complicated for practical use. Other methods which do not involve these errors (as, for instance, the use of two dynamometers whose fields have a common excitation adjustable in phase) are much to be preferred. If the excitation of the dynamometer is in phase with E_1 or with I_1, the equations are more complicated, but the general

order of the errors is similar to the above. If the excitation is in phase with E_2, the equation for ratio takes the form

$$\frac{E_1}{E_2} = \frac{R_1 + R_2}{R_2} \times \frac{1}{\cos\alpha \cos\phi} \times \left[1 + \left(\frac{R_1}{R_1 + R_2}\right) \times \left(\frac{R_2}{R_D}\right) \times \sin^2\alpha\right] \quad (5)$$

As the two factors indicating the error both have an effect in the same direction, there is no single value of R_D at which the ratio error is totally eliminated.

If $R_D = \frac{R_1 R_2}{R_1 + R_2}$, equation (5) becomes

$$\frac{E_1}{E_2} = \frac{R_1 + R_2}{R_2} \times \frac{1 + \sin^2\alpha}{\cos\alpha \cos\phi}$$

If $\alpha = \phi$, which would be very nearly true with this value of R_D,

$$\frac{E_1}{E_2} = \frac{R_1 + R_2}{R_2} \times \frac{1 + \sin^2\alpha}{1 - \sin^2\alpha}$$

This equation gives the following values

r	α	Correction-factor	Per cent error
1 deg.	30 min.	1.00008	0.008
2 deg.	1 deg.	1.00061	0.061
3 deg.	1 deg. 30 min.	1.00137	0.137

It is evident that a satisfactory accuracy can be attained with about 2 deg. phase angle. These results change but slightly for moderate changes of R_D.

SUMMARY

Ratio of voltages may be taken by the balance method with entire accuracy, if the detector is either self-excited or excited in phase with I_2, by keeping

$$R_D = \frac{R_1 R_2}{R_1 + R_2}.$$

If this value is even approximately maintained, errors are negligible.

With excitation in phase with E_1 or I_1, the errors are of a similar order of magnitude, but the equations involved are much more complicated, and the exact errors are much more difficult to determine.

With excitation in phase with E_2, the errors are never reduced to zero; but where the phase angle γ is 2 deg. or less, the error in ratio is only about 0.06 per cent if R_D is kept equal to or greater than the value in the above formula. This amount is negligible for ordinary purposes.

For phase angle, with any of the above connections, a result may be obtained by keeping R_D equal to the value given above, and doubling the angle obtained by direct calculation. It is, however, subject to considerable error if R_D varies, and correction is impracticable; therefore it is better to use some method which does not involve these errors, as for instance, the two-dynamometer method.

It should be noted that the above results are calculated for sine wave voltage. With a distorted voltage wave, or with slightly differing waves, harmonic currents flow in the detector which greatly complicate the theory. The actual additional errors caused by this are in general negligible for practical work. Where inductive devices are used to balance the voltage in the detector circuit, they do not, on account of wave form, wholly prevent the flow of current, and consequently only diminish, without entirely avoiding, the errors described above. The further discussion of these methods is not properly a part of this paper.

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MEASUREMENTS OF MAXIMUM VALUES IN HIGH VOLTAGE TESTING

BY C. H. SHARP AND F. M. FARMER

The breakdown strength of insulating materials is measured by the maximum voltage which they will withstand under given conditions. Tests are ordinarily made on alternating voltages, and the measurement of the maximum voltage is effected by indirect rather than direct means; that is, by measuring the virtual value of the voltage on either the primary or the secondary of the transformer and arriving at the maximum value by using a measured or assumed value of the peak-factor* of the wave. It is unfortunately true that this peak-factor is more often assumed than measured, and no doubt many tests of dielectric strength are inaccurate because of unsuspected changes in the wave-form produced by conditions of the test. Only in the spark-gap has an apparatus been available whereby a measure of the actual maximum value of the high voltage could be obtained. The spark-gap is however, a most uncertain piece of apparatus, the vagaries in the behavior of which have by no means been accounted for. Installed according to the Standardization Rules of the Institute, a spark-gap for measuring 250,000 volts requires a space such that no "extraneous" body comes nearer than 4 ft. 3 in. (129.4 cm.); that is, a clear space or room 8½ by 8½ by 8½ feet (259 cm.) is required. In view of this requirement, the spark-gap is a very large and cumbersome, as well as uncertain and unsatisfactory apparatus.

The arrangement here described is designed to give readings on a voltmeter of the maximum value of a high voltage wave.

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* The term "peak-factor" is used for the ratio of the maximum voltage of the wave to the virtual voltage.

The scheme is shown in Fig. 1. A series of condensers *C*, serving as a voltage divider, is connected across the high voltage line or from one side of the high voltage line to ground, if the transformer secondary is grounded. In parallel to the condenser C_1, which is grounded, is connected a rectifier or commutator *R* driven by a synchronous motor, the rectifier being connected in turn to an electrostatic voltmeter *V*. The commutator is adjusted to make instantaneous contact between the condenser and the voltmeter at the peaks of the waves. The voltmeter thus becomes charged to a potential corresponding to the maximum of the voltage waves and indicates this value. Inasmuch as the voltmeter is always charged in the same direction, it reaches its maximum charge after a few contacts of the brushes and after that draws no charging current from the condenser with which it is in parallel, except such as is necessary to supply leakage loss and to change the potential of the ungrounded side of the voltmeter with respect to the earth. Both of these charges should be relatively small. Hence the capacity of the electrostatic voltmeter does not change the multiplying ratio of the train of condensers, which is equal to the ratio of the capacity of the end condenser to that of the entire train, and the absolute value of the capacity of these condensers, be it large or small, has no influence. Of course for practical reasons the absolute capacity should not be too small.

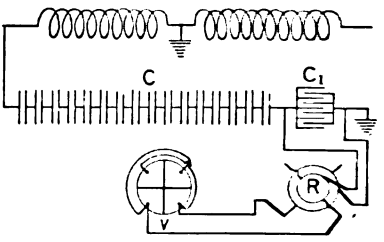

FIG. 1

The calibration of the arrangement may be carried out in two different ways, both of which assume that the virtual value of the high voltage can be measured.

Method 1. The synchronous motor is stopped in such a position that the brushes are making contact. Then the electrostatic voltmeter indicates a value proportional to the virtual value. By comparing this value with the known high tension voltage a calibration of the arrangement in volts, high tension, is obtained. The calibration is not, however, exactly the same for volts maximum unless the capacity of the voltmeter is negligible in comparison with that of the condenser with which it is in parallel. Otherwise, when connected permanently in parallel with the end condenser, it alters the multiplying ratio of the

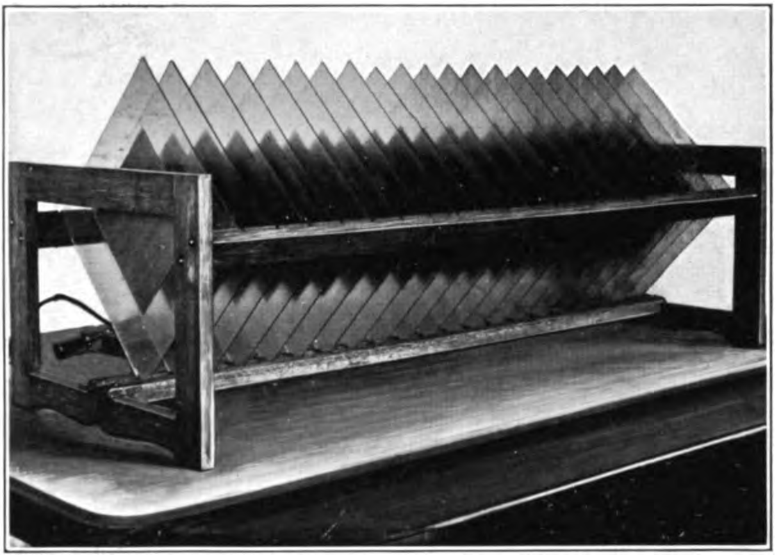

FIG. 2 [SHARP AND FARMER]

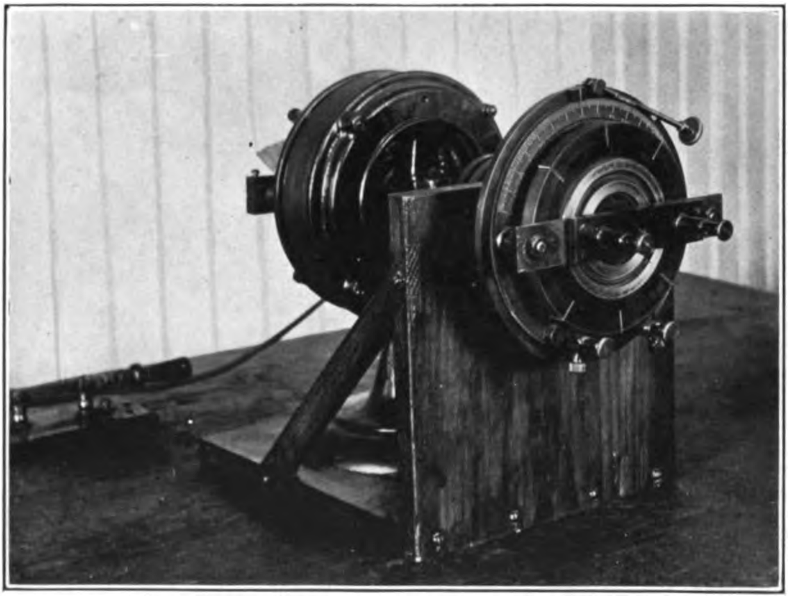

FIG. 3 [SHARP AND FARMER]

train, which, as explained above, is not the case in measuring maximum volts. By properly proportioning the condensers, the capacity of the condenser may be many times that of the voltmeter, and this method may be used, or in any case where the capacity of the voltmeter is known, a correction corresponding thereto may be applied.

Method 2. The position of the contact brushes may be shifted and their positions read on a graduated disk. By shifting these brushes to different positions and taking corresponding readings of the voltmeter, data may be obtained for plotting a wave-form curve. By finding the r.m.s ordinate of the curve and comparing it with the value in volts of the virtual voltage applied to the series of condensers, the multiplying power of the condensers is determined. This method of calibrating makes no assumptions as to the capacities and other properties of the condensers.

When once the calibration has been carried out, the electrostatic voltmeter may be graduated to read directly values of high tension volts; with the brushes set to the right position, the apparatus reads the maximum voltage used in a breakdown test.

The actual apparatus constructed and used in applying the above method is as follows:

The condenser train (Fig. 2) consists of 21 glass plates 9 by 9 in. (23 cm.) coated on each side with tin-foil 5 by 5 in. (13 cm.) and having a capacity of around 0.0006 microfarad each. These are supported on a rack of dried hardwood impregnated with oil and are immersed in a metal tank filled with transformer oil. The tank is grounded and serves to prevent variations in the capacity of the condensers due to changes in outside conditions. The oil is required to prevent corona discharge at high tension and leakage due to dirt, moisture, etc., on the plates, either of which would cause a change in the impedance and introduce an error.

Since the electrostatic voltmeter has a comparatively short useful working range, the train needs to have a variety of multiplying ratios. For this reason a sub-divided mica condenser is used as the grounded condenser, the one to which the voltmeter is connected. This condenser can be adjusted to give any required multiplying ratio. It need not be placed in the oil tank.

The commutator (Fig. 3) consists of a disk of hard rubber into which thin brass contactors are set in such a way that they strike the brushes. The brushes must not touch the rubber surface for if they do they are liable to get a difference of potential through difference in friction, and to affect the voltmeter reading. The brush-holder is adjustable and its position can be read on a divided circle. A slow-motion tangent screw is provided for adjusting the position of the brushes accurately to the peak of the wave. The commutator is driven through an insulating coupling by a small synchronous motor. A Kelvin multicellular electrostatic voltmeter is used, fitted with a mirror and scale for exact reading. This is surrounded by a grounded electrostatic shield. The capacity of this voltmeter is very low, being approximately 0.00007 microfarad.

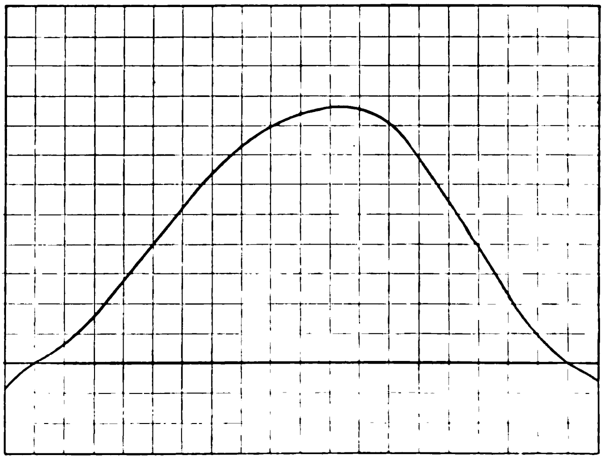

FIG. 4

This apparatus has been tested on a transformer rated at 50 kv-a., 250,000 volts, having the middle point of the secondary grounded. The condenser train was connected from one leg of the transformer to earth and thus was affected by one half the total voltage. Calibrations were made by both methods given and the results were concordant with each other on a smooth wave form, nearly sinusoidal, and on a badly distorted wave; also on frequencies of 25 and 60 cycles per second. During the tests, which are not as yet completed, voltages as high as 140,000 volts, peak value, have been impressed on the apparatus.

The wave-forms and peak-factors as found with this apparatus were checked by tracing the wave-form by the standard instantaneous contact method and also by the oscillograph.

With the smooth wave (Fig. 4) of the 25-cycle current, the peak-factor as found by the standard method was 1.50; as found from the wave-form traced with this apparatus it was 1.51;

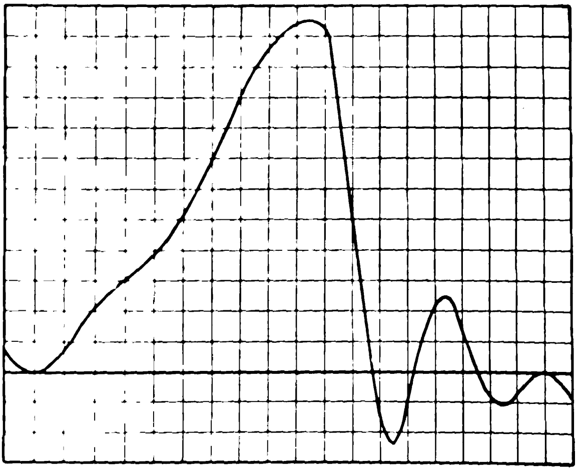

FIG. 5

as found from maximum and virtual voltage readings of the electrostatic voltmeter it was 1.52.

With the distorted wave (Fig. 5) difficulty was encountered

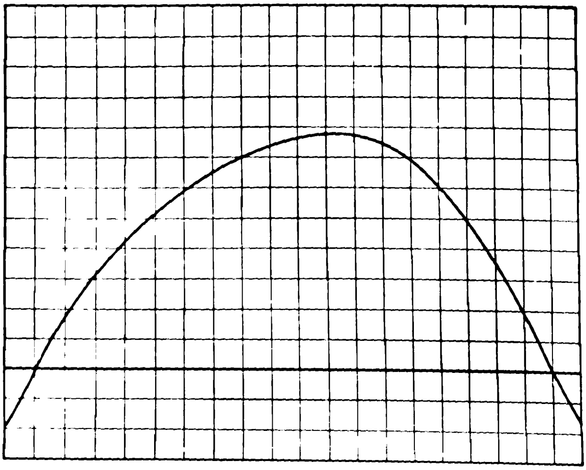

FIG. 6

in tracing the form by the electrostatic voltmeter. This arose from the fact that the readings of the voltmeter, being proportional to the square of the voltage, become very small at low voltages, and from the further fact that the instrument gives no indication of a change of polarity. Hence it was practically impossible to say, from readings of the voltmeter, on which side of the zero line the additional loops of this wave lay. To apply this method, therefore, to a wave which is badly distorted near the zero value would require more delicate means for measuring voltages.

The peak-factor of this wave as determined by the standard methods was 2.00; as determined from maximum and virtual voltage readings on the electrostatic voltmeter it was 2.00; so that this simple method of calibrating held even in this extreme case.

With the 60-cycle smooth wave (Fig. 6) the wave-form by the standard method gave a peak factor of 1.35_4; the voltmeter wave-form gave 1.36 and the maximum and virtual voltage readings gave 1.36_8.

The agreement of the results of the different method is sufficiently close for work of this character. There seems therefore to be no difficulty in calibrating the apparatus to give either maximum or virtual volts of the high voltage line. The use of this apparatus should relieve high voltage tests of the uncertainty as to the actual maximum voltage which is being applied. The elimination of guess work as to this fundamental quantity cannot fail to give more satisfactory results in this important class of testing.

It may be noted that if the testing transformer has low voltage measuring taps from the high voltage winding, the commutator and voltmeter may be used directly without the condenser train. The change in range of the voltmeter cannot then be effected so easily, but considerable complication is avoided.

The above work has been performed at the Electrical Testing Laboratories with a view to realizing improvements in the accuracy of testing. The writers desire to express their high appreciation of the very efficient and enthusiastic assistance of Mr. E. D. Doyle in carrying out the experimental work.

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HOT WIRE INSTRUMENTS

BY A. W. PIERCE AND M. E. TRESSLER

In this paper we shall point out the special field for use of hot wire instruments, and support our statements by facts and figures drawn from long association with this particular type of instrument.

There is a large gap between pivoted instruments of the dynamometer or moving iron type, and the sensitive reflecting dynamometer, voltmeter or ammeter. This gap can be reduced by the use of hot wire instruments.

The lowest range pivoted voltmeter of the dynamometer type for use on alternating currents, with which we are familiar, requires 7.5 volts for full scale deflection, and has an appreciable frequency error even at 60 cycles per second, in addition to a temperature coefficient which must be taken into account in accurate measurements.

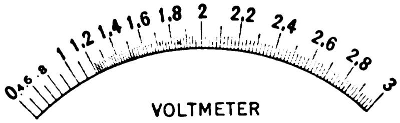

FIG. 1

The voltmeter scale shown in Fig. 1 was traced from one of several three-volt hot wire instruments which have been in use in a large testing department for several years. These instruments have no temperature coefficient, and when made with a properly aged hot wire have a very small zero error due to changes in temperature of the instrument as a whole or in part. The inductance of the hot wire is practically zero, and the instruments give equally accurate indications on direct and alternating voltages at all frequencies lower than 500 cycles per second. These voltmeters can be relied upon within one-half scale division as low as 1.2 volts, as shown by the following check made on direct current against a carefully calibrated laboratory standard voltmeter:

TABLE I

Standard reads..	3	2.8	2.6	2.4	2.2	2	1.8	1.6	1.4	1.2
Instrument reads........	3.00	2.795	2.60	2.395	2.195	2.00	1.795	1.60	1.40	1.195

These voltmeters can be used with suitable series resistance to measure higher voltages than three volts and require about 0.2 ampere for full scale deflection.

Hot wire ammeters can be made for a full scale range of 0.25 ampere, which will indicate 0.1 ampere with an accuracy closer than 1 per cent.

Fig. 2 shows a scale traced from one of these instruments in actual use.

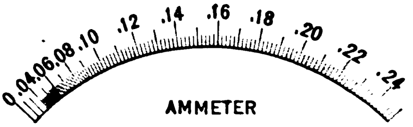

FIG. 2

0.25, 0.5, 0.75, 1, 1.5, 3, 5 and 6-ampere instruments can be made which will take all of the current measured through the hot wire and are not affected by wave form, frequency below 500 cycles per second, or stray fields. The *IR* drop and I^2R losses of these instruments will compare favorably with those of moving iron ammeters of corresponding ranges, as shown in Table II.

TABLE II

Capacity in amperes	*IR* volts	I^2R watts
	Iron vane ammeters	
5	0.63	3.15
2	1.52	3.04
7	9.34	6.54
	Hot wire ammeters	
6	0.25	1.5
5	0.3	1.5
1.5	1	1.5
1	0.75	0.75
0.75	1	0.75
0.5	1.5	0.75
0.25	3	0.75

Table III, which was copied from the calibration record of a hot wire ammeter adjusted for a series range of 0.25 ampere with shunts for 0.5, 1, 2 and 4 amperes, gives a fair idea of what can be reasonably expected from such an instrument when carefully used. These checks were taken on the one-ampere scale against a potentiometer and standard resistance.

TABLE III

The first line gives the settings of the standard; the dates and corresponding instrument readings follows.

Date	1.000	0.900	0.800	0.700	0.600	0.500	0.400	0.300	0.200
2-25-11	0.999	0.900	0.800	0.700	0.601	0.501	0.400	0.300	0.201
3-18-11	0.998	0.899	0.800	0.699	0.600	0.500	0.400	0.298	0.200
4-7-11	0.999	0.899	0.800	0.699	0.600	0.500	0.399	0.298	0.199
5-5-11	0.997	0.898	0.798	0.699	0.599	0.500	0.399	0.298	0.200
6-3-11	0.999	0.900	0.800	0.699	0 600	0.500	0.399	0.299	0.200
7-13-11	1.000	0.900	0.800	0.699	0.599	0.499	0.398	0.298	0.199
8-4-11	1.000	0.900	0.800	0.700	0.600	0.500	0.399	0.298	0.199
9-6-11	1.000	0.901	0.801	0.700	0.600	0.500	0.400	0.298	0.199
9-29-11	1.000	0.902	0.802	0.701	0.601	0.501	0.400	0.299	0.200
10-25-11	0.999	0.900	0.801	0.699	0.600	0.500	0.399	0.298	
11-25-11	1.000	0.900	0.800	0.700	0.600	0.500	0.399	0.298	
12-29-11	0.999	0.900	0.800	0.700	0.600	0.500	0.400	0.298	
2-1-12	0.999	0.900	0.800	0.700	0.600	0.500	0.399	0.298	
2-21-12	1.000	0.901	0.801	0.700	0.600	0.500	0.400	0.299	

For ranges higher than six amperes shunts can be used with the instruments, and currents as high as 2000 amperes have been measured in this way. A high range hot wire ammeter has an energy consumption greater than that of a good moving iron ammeter and current transformer. But it has the advantage over such a combination in that it can be checked on direct current and used on alternating current of commercial frequencies without any appreciable error. It costs less, is easier to read and manipulate than a Kelvin balance or Siemens dynamometer. It is therefore well suited for use as a working standard for the calibration of moving iron instruments and current transformers.

Because of their very small inductance and capacity, hot wire instruments are better suited for measuring high frequency currents than any coil instrument, particularly for currents which come within the six-ampere range of the self-contained instruments. Even where shunts have to be used, the errors caused by unequal distribution of current between the instrument and shunt on direct current and at high frequencies will be less than those caused by the self-inductance of series transformer and coil instruments.

Conclusion. Hot wire instruments can be used to good advantage, (1) In measuring small alternating currents and voltages; (2) as general utility instruments for indiscriminate use on alternating and direct current and for checking iron vane ammeters; (3) for measuring high frequency currents where coil instruments would be useless.

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INCANDESCENT LAMPS AS RESISTANCES

BY T. H. AMRINE

Incandescent lamps have long been used as resistances in electrical measurements, but they have not been used over nearly as wide a range and variety of work as they might be. The reason for this is probably that information as to the resistance values and characteristics is not generally available and for that reason the proper lamps can not be easily selected. It is the purpose of this paper to emphasize the value of incandescent lamps as resistances, to give some information regarding the resistance characteristics, ranges of resistance and current carrying capacities available, and such other information as will assist one in the selection of the proper lamps for any particular purpose.

The principal advantages of lamps as resistance are, of course, their general availability and their low cost. These are of especial importance in experimental work, where delays and expense under the best conditions often seriously impede progress. A wide range of lamps suitable for use as resistance can be kept in stock in a laboratory with a very small outlay of money and if properly selected and used will to a large extent take the place of a much more expensive equipment of rheostats, resistances, etc. The list price of a lamp which will carry 0.11 amperes and has a resistance of 2150 ohms is only 18 cents, which is probably less than the cost of an equal amount of resistance of like carrying capacity in any other form.

The fact that a very wide range of temperature coefficient of resistance is available in incandescent lamps is well known, perhaps, but is taken advantage of to a much less extent than is possible. Commercial lamps are now being made with untreated carbon, treated carbon, metallized carbon, tantalum and tungsten filaments. These materials range in temperature coefficient from a pronounced negative to a large positive value. In Figs. 1, 2 and 3 are given curves plotted between per cent normal current and per cent of cold resistance, for lamps with the various filament materials which are now in commerical use, and for a few forms of treated carbon (Fig. 3) that are not in commercial use but which have been made specially. These give an idea of the range in temperature coefficient available. It is seen from these curves that for limited ranges almost any desired change of resistance with change of current can be selected, ranging from a pronounced decrease to a very large increase as well as a practically negligible change of resistance with current.

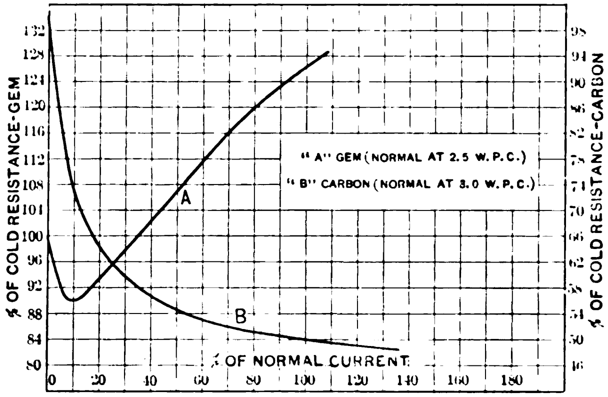

FIG. 1

In connection with these curves it may be necessary to explain that in under-going the "flashing" or "treating" process carbon filaments decrease in resistance an amount depending upon the amount of treatment given. Hence, the curve marked "50 per cent treatment" would refer to a filament which had been treated until its resistance had decreased to 50 per cent of its initial resistance. Commerical carbon filaments are treated to approximately 60 per cent of their initial resistance.

Below is given, for the various commercial filaments, a table of exponents X in the equation $\frac{R_1}{R_2} = \left(\frac{F_1}{F_2}\right)^x$ which gives the change in resistance R with changes in F, where F represents the various quantities, candle-power, efficiency, volts, watts and current.

TABLE I

F	Values of *X* for				
	Untreated carbon	Treated carbon	Metallized carbon	Tantalum	Tungsten
Candle-power	—0.045	—0.015	0.050	0.060	0.115
Efficiency	0.070	0.020	—0.075	—0.100	—0.200
Volts	—0.310	—0.075	0.230	0.260	0.420
Watts	—0.135	—0.035	0.130	0.150	0.260
Current	—0.235	—0.070	0.300	0.350	0.720

These are average exponents which are approximately correct over a range of 20 per cent either side of the normal voltage of the lamps. By their use the resistance corresponding to any value of the function *F* can be determined, knowing the resistance at some other value, say normal, of the same function.

Below is given a table which shows the maximum resistance which is available in commercial lamps for various ampere capacities.

TABLE II

Type of filament	Amperes	Maximum resistance obtainable at given amperes	Commercial rating
Untreated carbon	0.077	1690	10-watt 130-volt
" "	0.110	2520	30 " 275 "
Treated carbon	0.154	845	20 " 130 "
" "	0.365	754	100 " 275 "
" "	0.920	141	120 " 130 "
" "	1.00	75	1-ampere resistance lamp
" "	2.00	13	2- " " "
" "	3.00	8	3 " " "
" "	3.85	36	500-watt, 130-volt heater lamp
Metallized carbon	0.231	563	30-watt, 130-volt " "
" "	0.462	282	60-watt 130- "
" "	0.77	169	100 " 130 "
Tungsten	0.077	1690	10 " 130 "
"	0.145	1900	40 " 275 "
"	0.218	1260	60 " 275 "
"	0.364	760	100 " 275 "
"	0.510	530	150 " 275 "
"	0.910	300	250 " 275 "
"	1.18	110	150 " 130 "
"	1.92	68	250 " 130 "
"	3.84	34	500 " 130 "
"	5.00	20	500 " 100 "

The resistances given above are " normal " resistances, that is, the resistances at the rated normal voltages of the various lamps. The resistances at other currents can be obtained by reference to the curves of Figs. 1, 2 and 3 or by use of the exponents given in Table I.

In almost all cases lamps of lower resistance, but having about the same ampere carrying capacity, can be obtained in regular commercial lamps.

In order to select the proper resistance lamps for any purpose it is necessary to have the following information:

1. Resistance.

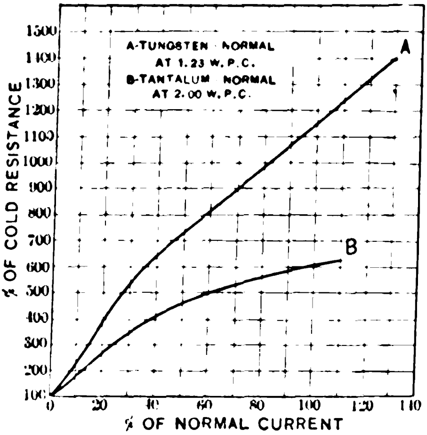

FIG. 2

2. Current carrying capacity.
3. Degree of incandescence permissible.
4. Change in resistance with change in current that is allowable.

In selecting the lamp it is first necessary to know the per cent normal current at which the various types of lamps will give the desired degree of incandescence. Table III will enable one to choose these values.

The degree of incandescence permissible depends upon whether or not light is objectionable, upon the desirability of constancy over long periods of use and upon the necessity of long life of the lamps. The average total life of an incandescent lamp at the commercial efficiencies can be assumed at 1000 hours. A one per cent decrease in current below normal will increase the life from 11 to 24 per cent, depending upon the type of filament, so that if the lamps are operated a few per cent below normal they will give a very satisfactory life. Operation above normal will, of course, decrease the life in the same ratio.

TABLE III

	Per cent of normal current				
	Untreated carbon	Treated carbon	Metallized carbon	Tantalum	Tungsten
Dull red..................	12	14	17	20	23
Cherry red.................	18	20	24	26	28
Yellow red.................	28	30	33	35	38

From the curves of Figs. 1 and 2 one can select the type of lamp which will give most nearly the desired current-resistance change at the proper degree of incandescence. Knowing the per cent current at which the lamp is to be operated one can obtain from the curves the corresponding per cent resistance, and from this can be calculated the normal resistance of the proper lamp. From the normal resistance and normal current the voltage and wattage of the lamp can be determined. When

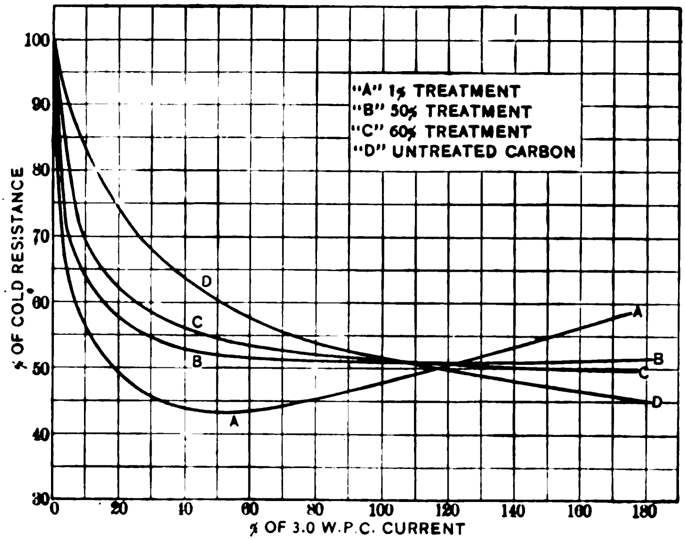

FIG. 3

possible, of course, it is very desirable to select a lamp which is a regular commercial product and so avoid the inevitable delay and increased cost of a special lamp.

As examples of uses to which incandescent lamp resistances have been put other than the familiar laboratory use in lamp banks, etc., a brief description of some of the methods which have been utilized in the laboratory with which the writer is connected will be cited.

Carbon lamps seasoned at about 109 per cent of their normal voltage for a period of 12 hours* are carefully rated for volts at various ampere values and are used in the factories for checking ammeters. By this method, with a calibrated voltmeter and a few lamps one can check portable voltmeters and ammeters in as satisfactory a manner as with both standard voltmeter and ammeter.

Extensive use is made of a four-lamp bridge which is essentially the same as the old Howell indicator. In this bridge four lamps are arranged as shown in Fig. 4, in which *A* and *D* represent lamps having a different current-resistance relation from lamps *B* and *C*. For instance, *A* and *D* may be carbon lamps *B* and *C* and metallized carbon lamps, the most sensitive combination which utilizes commercial lamps being with untreated carbon lamps for *A* and *D* and tungsten lamps for *B* and *C*. If, by means of the small adjustable resistance *R*, the galvanometer *G* is brought to zero for any current through *ABCD*, then any change from that current will produce a deflection of the galvanometer. This arrangement is used to enable one to hold the voltage on a given circuit constant by putting the terminals *a d* across the line, bringing the line to the desired voltage by the use of a voltmeter and then adjusting the galvanometer to zero by means of *R*. With a proper bridge and an ordinary portable galvanometer a small change, say 0.1 per cent in the voltage of the line is made evident by a considerable deflection

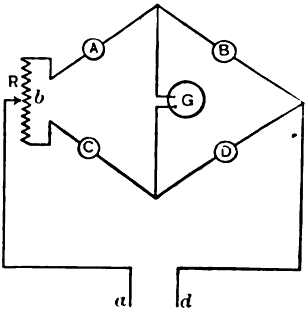

FIG. 4

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*Before being used as resistances for any purpose which requires careful resistance adjustment, all incandescent lamps should be seasoned by burning for a period sufficiently long to bring them to a constant resistance value.

of the galvanometer. By placing a bridge arrangement such as this in series with a line the line current can be held to a constant value in a similar way.

A photographic recording alternating-current voltmeter of high sensibility which was developed by Mr. L. T. Robinson utilizes a four-lamp bridge similar to the one described, in connection with a reflecting dynamometer.

A temperature control device has also been made by using a small tungsten lamp as one arm of a bridge and placing it in the oven whose temperature was to be kept constant. The bridge is brought to a balance by adjustment of the other arms while the temperature is held constant at the correct value by means of a thermometer. After being set thus the oven can be readily held at the proper temperature by reference to the galvanometer.

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RESONANT CIRCUIT FREQUENCY INDICATOR

BY W. H. PRATT AND D. R. PRICE

The object of this device is to supply a method for accurately measuring the frequency of a circuit, to give a large scale deflection on the instrument for a small percentage change in frequency and to obtain readings which are accurate under all ordinary conditions of wave form, voltage variation and temperature.

The electric circuit whose impedance is the most sensitive to a change in frequency is that circuit which contains inductance and capacity connected either in series or parallel; the degree of sensitiveness of such a circuit can be changed and varied through a wide range at the convenience of the designer. These two characteristics admirably adapt this circuit to the construction of a frequency indicator and indirectly to the construction of a speed indicator, provided that it can be applied in a practical form.

Being extremely sensitive to a change of frequency it follows that it is also sensitive to a change in the constants of its own constituent parts (although in this case to a less degree, as will be shown) and the application of this circuit in a practical form for this reason presented some difficulties at first.

The theory of resonance is of course well understood, but in practise certain limitations are presented which in some cases make it very difficult to approach theoretical values of current in a tuned or partially tuned circuit. Theory presupposes a perfect inductance, a perfect condenser, and a perfect resistance, when as a matter of fact a perfect inductance and a perfect condenser are never realized. By a perfect inductance is meant a circuit having inductance alone with no losses—the same applies to a perfect condenser.

In order that the circuit be resonant or tuned, or partially tuned, the inductance and condenser must be of such a nature that the excess lines of force must be free to collapse as soon as the current flowing in them begins to diminish. On this characteristic the degree of success in tuning and the approach to theoretical values of current depends entirely. Numerous mechanical analogies of elastic and inelastic bodies will suggest themselves.

It is possible to reach almost theoretical conditions and to obtain almost theoretical frequency impedance curves by using an air core inductance and an air dielectric condenser. Space limitations, however, place them entirely out of the question for use on instrument work.

Owing to this limitation of space it is necessary to adopt an iron core inductance and a compact condenser with a solid dielectric of a specific inductive capacity somewhat greater than that of air. These two substances, iron and a solid dielectric, introduce losses and variations and other difficulties. An iron core inductance has the following faults: hysteresis loss, eddy current loss, magnetization curve not a straight line, and the variation in form due to temperature and mechanical trouble.

Of these the all-important one is hysteresis loss. Not only does this loss appear as an added resistance to the circuit, but it absolutely destroys all resonance if present beyond a certain degree; for if the lines of force which are once established in a circuit do not collapse when the source of current is withdrawn there can be no resonance whatever. This also will suggest mechanical analogies. It is then very important to keep down the hysteresis in the inductance element. On account of hysteresis it was found impossible to tune a closed magnetic circuit inductance.

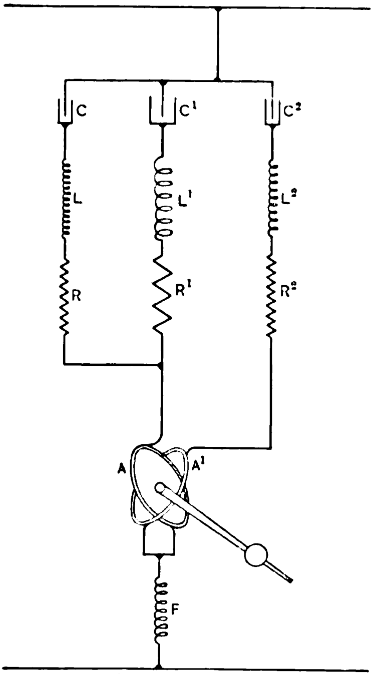
The eddy current loss tends to lower the inductance of the circuit and acts as an added resistance. The amount of lowering of the inductance will have a temperature coefficient and for this reason the eddy currents should be kept as low as practicable. However, the eddy currents do not affect the tuning, like hysteresis, and this loss can be calibrated with the other parts of the circuit. The other variations due to the use of iron can be reduced to a low value by proper designs.

All the other troubles inherent to condensers can be overcome by proper design, so as not to effect this work, and all the other troubles met with in high-frequency tuning are not apparent in frequencies such as 60 cycles.

The constituent parts of the circuit were, therefore, designed as follows:

The inductance was wound on a laminated iron core which had an air gap in its circuit, and the flux was kept low so as to be well below the saturation point.

The condenser was made by the vacuum process, which insures a permanent high insulation, and low internal heating. It was designed to operate at a voltage well below the safe working voltage. The resistances were all zero temperature coefficient metal.



C C^1 C^2 CONDENSERS
L L^1 L^2 INDICATORS
R R^1 R^2 RESISTANCES
A A^1 .. MOVING COIL OF INSTR.
F.... FIELD COIL OF INSTR.

FIG. 1.

A standard instrument was used with the capacities, inductances and resistances in a separate box. This standard instrument was essentially a field and two armatures set at an angle with each other and having a common diameter through which the shaft passed.

The external box contained three separate circuits, each having an inductance, a capacity and a resistance in series. Two of these circuits were identical and the third was designed for a much smaller current carrying capacity, for a reason to be explained.

One of the main circuits was adjusted so as to be in resonance at about 70 cycles; the other main circuit was adjusted so as to be in resonance at about 58 cycles. The third circuit was adjusted so as to be in resonance at about 36 cycles. This last circuit was connected in parallel with the circuit adjusted to be in resonance at 58 cycles. The circuit adjusted at 70 cycles was connected to that armature coil on the instrument which tended to move the needle up. The other two circuits were connected to the armature which tended to make the needle move down. The armatures were in series with the field coil.

The center of the scale was marked for 60 cycles, the left-hand end being 55 and the right-hand end 65. It was possible to get a 6-inch (15-cm.) movement for a change in frequency from 55 to 65 very easily, and it was also possible to get a 6-inch movement for a change in frequency from 60 to 61, on the same instrument. There appears to be almost no limit to the sensibility of this arrangement. The actual working of the apparatus is self-evident and needs no explanation.

When the frequency drops very low, for instance, 30 or so, the small auxiliary circuit supplies torque to prevent the needle from again going on the scale, due to the absence of torque from the main circuits, since both are far away from their resonant frequency.

When made up in a practical form, this instrument exhibits only a trace of variation, due to wave form, voltage or temperature.

The connections of the instrument are shown in Fig. 1.

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WHEATSTONE BRIDGE—ROTATING STANDARD METHOD OF TESTING LARGE CAPACITY WATT-HOUR METERS

BY C. H. INGALLS AND J. W. COWLES

There are two general classes of large capacity watt-hour meters, alternating-current and direct-current. The meters used for alternating current are almost invariably of the induction type, generally five-ampere meters used in conjunction with current transformers, or both current and potential transformers. A facile and accurate method of testing these meters is by means of an induction type of rotating standard which by means of standard instrument transformers may be made available for testing any a-c. meter of any capacity, with a precision well within commercial limits.

Where large capacity direct-current meters are to be tested, however, the problem is somewhat more difficult. The method usually chosen is the indicating instrument-stop-watch method, by which method the energy delivered to the meter under test is measured by indicating instruments (voltmeter, millivoltmeter and shunt) and the speed of the meter determined by a stop watch. Where the load is constant, this method is satisfactory, but for power circuits similar to street railways, where there are rapid fluctuations of considerable magnitude, this method is not desirable.

The rotating standards have many advantages when used on loads of this character, but unfortunately they are not made commercially of a capacity exceeding 150 amperes and, unlike milli-voltmeters, it is not advisable to use them directly with shunts, with the possible exception of the mercury flotation type of standard.

In order to adapt the rotating standard to the testing of meters of 1000 or 2000 amperes capacity a differential galvanometer was devised by Prof. F. A. Laws, of the Massachusetts Institute of Technology which was so arranged that a standard of moderate capacity could be used. It consisted essentially of two current coils wound in opposition, having between them a pivoted coil of fine wire. The apparatus and connections are shown diagrammatically in Fig. 1. The coil *a* is of few turns (actually a straight copper bar) but of sufficient capacity to carry the full line current. Coil *b* has the same current capacity as the rotating standard and with such a number of turns, that by adjusting the resistance *d*, the effect of the current in *b* will counterbalance the effect of the current in *a* on the coil *c*.

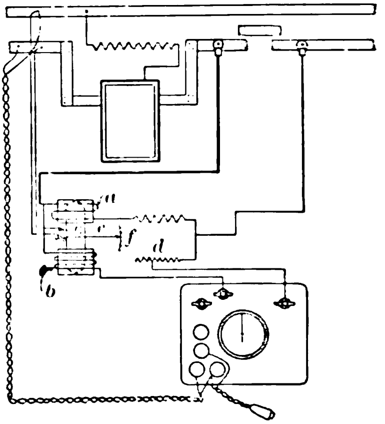


FIG. 1

With this condition of balance, which is indicated by the pointer *e*, the ratio of the two currents $\frac{Ia}{Ib}$, also $\frac{Ia + Ib}{Ib}$, is a constant, and the rotating standard will measure a definite percentage of the total energy delivered to the meter under test. This ratio and percentage are determined in the laboratory by actual measurements. The differential galvanometer as described above is subject to the influence of external fields, and a modification of this method was devised by the writer, based on the general principle of a Wheatstone bridge. The arrangement of the resistances and the rotating standard is shown diagrammatically in Fig. 2, where *a*, *b*, and *c* are fixed resistances forming three arms of the bridge, the rotating standard and the adjustable resistances *d* and *e* forming the fourth arm. When the potential differences between the terminals of the two resistances *a* and *b* are the same, (and since they have one terminal in common, this is indicated by the galvanometer reading zero) the current in *a* is to the current in *b* as the resistance of *b* is to the resistance of *a*, or

$$\frac{Ia}{Ib} = \frac{Rb}{Ra} \text{ or } \frac{Ia + Ib}{Ib} = \frac{Ra + Rb}{Rb}$$

Ra and *Rb* are constant, therefore $\frac{Ia + Ib}{Ib}$ is a constant as as long as the galvanometer indicates a zero reading. $Ia + Ib$ is the current measured by the meter under test and *Ib* is the current measured by the rotating standard, therefore the rotating standard measures a certain definite percentage of the current supplied to the service meter. This percentage may be computed from known values of *Ra* and *Rb* or preferably by actually measuring the values of *Ia* and *Ib*. The condition of balance between *a* and *b* is obtained by adjusting the resistances *d* and *e*, *d* being a strip of resistance metal used for coarse adjustments and *e* a carbon compression rheostat used for the fine adjustment. The three resistances *a*, *b*, and *c* are preferably made

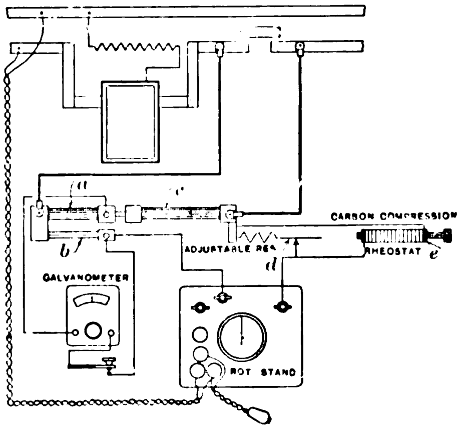
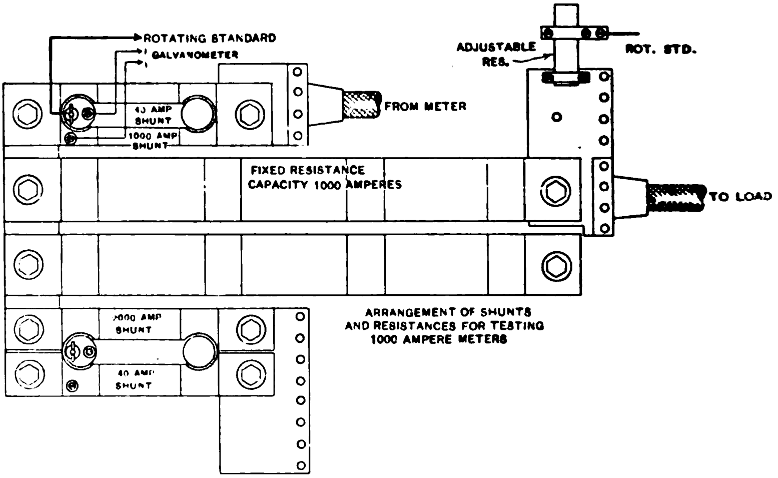


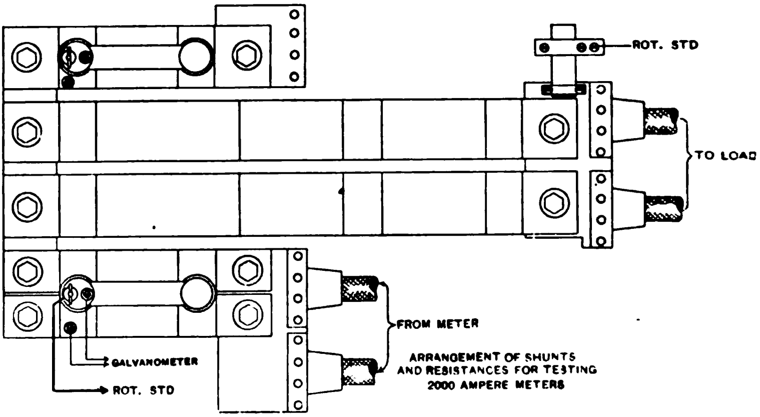
FIG. 2

of manganin in the same form as instrument shunts, as manganin has a negligible temperature coefficient and low thermal effect. *a* and *c* should be of a current capacity sufficient to carry the full line current and *b* approximately 40 to 50 amperes. The full load drop in potential is 100 millivolts each for *a* and *b* and 400 millivolts for *c*. Any change in the resistance of the rotating standard due to the temperature coefficient of the copper current windings or change in the contact resistance is readily compensated for by the rheostat *c*, but in practise it is found that after the preliminary adjustment very little further change is required. It is quite necessary for accurate work, however, to use material that have very small thermoelectric effect with each other, as in the first apparatus made up for trial more trouble was experienced from this source than any other. By using manganin for the resistances no difficulty from this source will be experienced.



ARRANGEMENT OF SHUNTS AND RESISTANCES FOR TESTING 1000 AMPERE METERS

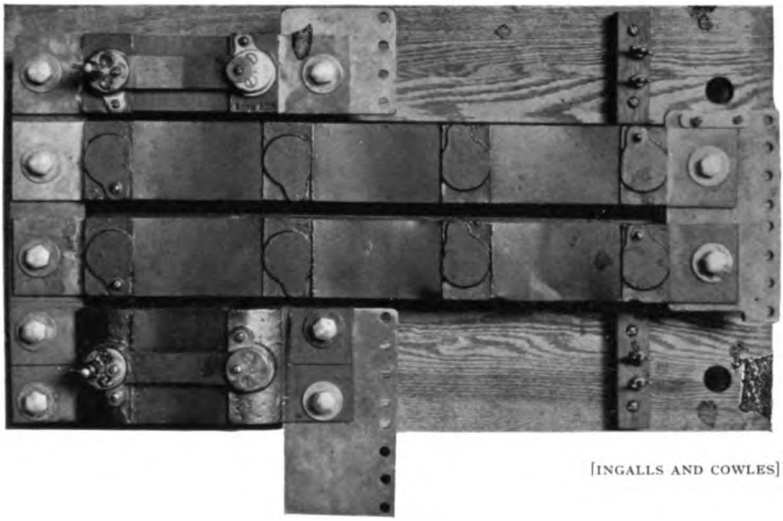
FIG 4



ARRANGEMENT OF SHUNTS AND RESISTANCES FOR TESTING 2000 AMPERE METERS

FIG. 5

Fig. 3 shows the arrangement of the resistances for testing both 1000-ampere and 2000-ampere meters, Fig. 4 the connections for testing 1000-ampere meters and Fig. 5 the connections for 2000-ampere meters. Fig. 6 is areproduction of a



[INGALLS AND COWLES]

FIG. 3

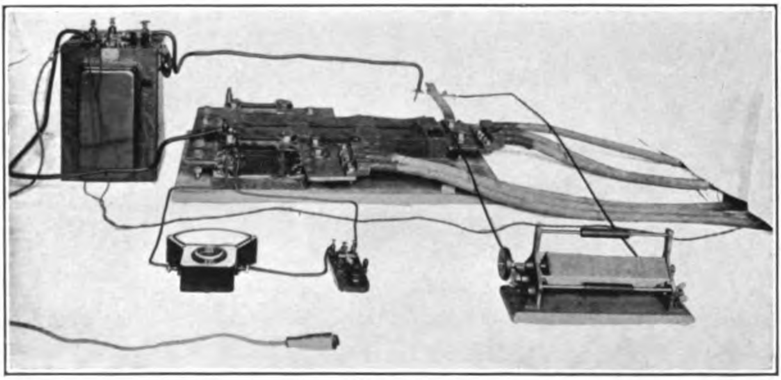


FIG. 6

[INGALLS AND COWLES]

photograph of the entire equipment, except the chest used for transporting the resistances and cables. This chest is approximately 32 by 19 by 14 in.

In using the direct-current rotating standard care should be exercised to guard against the influence of external fields, and since this apparatus is designed for use in places where large currents are involved, precaution should be taken either to take two series of readings, one series to be with both the current and potential leads of the rotating standard reversed, or to change bodily the position of the standard 180 deg. and take a series of readings in both azimuths. In either case the average of the two series should be used.

Following are the results of tests on various 550-volt meters supplying street railways. In some instances the current varied from zero to the full capacity of the service meter during the test.

TEST NO. 1.—2,000-AMPERE, 550-VOLT TWO-WIRE METER

Position of standard		Revs. of standard	Average	Correct revolutions	Per cent of accuracy of service meter
A	0 deg.	23.42			
		23.52			
		23.29			
		23.46	23.42	24.18	103.2
B	90 deg.	23.41			
		23.37			
		23.51			
		23.52	23.45	24.18	103.1
C	180 deg.	24.20			
		24.11			
		23.96			
		24.02	24.07	24.18	99.5
D	270 deg.	24.17			
		24.39			
		24.17			
		24.13	24.22	24.18	99.8

Average A and C..	101.35
Average B and D..	101.45
Average A, B, C and D....................................	101.4

TEST NO. 2.—600-AMPERE, 550-VOLT TWO-WIRE METER

VERY FLUCTUATING LOAD ON THIS METER.

Position of standard		Revs. of standard	Average	Correct revolutions	Per cent of accuracy of service meter
A	0 deg.	10.81			
		10.92			
		10.96			
		10.79	10.87	11.48	105.6
B	90 deg.	11.45			
		11.39			
		11.47			
		11.39	11.42	11.48	100.6
C	180 deg.	11.79			
		11.69			
		11.84			
		11.76	11.77	11.48	97.6
D	270 deg.	11.31			
		11.23			
		11.20			
		11.29	11.26	11.48	102.0

Average of A and C....................................	101.60
" " B and D....................................	101.30
" " A, B, C and D..............................	101.45

TEST NO. 3.—2000-AMPERE, 550-VOLT TWO-WIRE METER

Position of standard		Revs. of standard	Average	Correct revolutions	Per cent of accuracy of service meter
A	0 deg.	19.52			
		19.25			
		19.29			
		19.59	19.41	19.36	99.8
B	90 deg.	19.46			
		19.52			
		19.64			
		19.75	19.59	19.36	98.8
C	180 deg.	20.13			
		19.94			
		19.76			
		20.04	19.97	19.36	97 0
D	270 deg.	19.71			
		19.44			
		19.62			
		19.50	19.57	19.36	99.0

Average of A and C....................................	98.4
" " B and D....................................	98.9
" " A, B, C, and D..............................	98.65

TEST NO. 4.—1200-AMPERE, 550-VOLT TWO-WIRE METER

Position of standard		Revs. of standard	Average	Correct revolutions	Per cent of accuracy of service meter
A	0 deg.	14.71			
		14.60			
		14.74			
		14.62	14.67	14.50	99.0
B	90 deg.	14.51			
		14.63			
		14.62			
		14.65	14.61	14.50	99.2
C	180 deg.	13.88			
		13.74			
		13.74			
		13.73	13.77	14.50	105.2
D	270 deg.	13.82			
		13.94			
		13.80			
		13.85	13.85	14.50	104.6

Average of A and C	102.1
" " B and D	101 9
" " A, B, C, and D	102.0

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THE TESTING OF INSTRUMENT TRANSFORMERS

BY P. G. AGNEW AND F. B. SILSBEE

The determination of the ratio and phase angle of instrument transformers has now become a very important part of the work of electrical testing laboratories. The method now almost universally used in accurate work depends upon the potentiometer principle. Various modifications of this method have been suggested and used*. A modification of the method has recently been developed at the Bureau of Standards which, while involving no entirely new principles, possesses some distinct advantages over any of these.

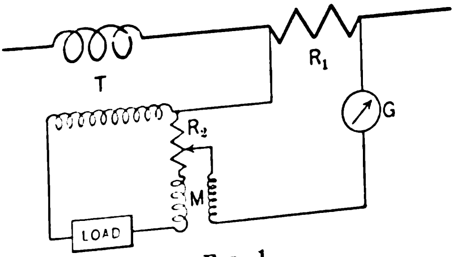

FIG. 1

The connections for the current transformer are shown in Fig. 1. Current from the source flows in series through the primary winding T of the transformer under test and through a standard non-inductive low resistance shunt R_1. The secondary current flows through the normal load of instruments, through the primary winding of a variable mutual inductance M and through a non-inductive resistance R_2, a variable part of which may be included in the galvanometer circuit. The resistances R_1 and R_2 have values inversely proportional to the currents flowing in them so that the IR drop is the same in both. The potential terminals are connected so that these equal voltages are in opposition and if there were no phase difference between them no current would flow through the vibration galvanometer G. On account of the phase-displacement in the transformer, however, it is necessary to introduce an e.m.f. in quadrature with $I_2 R_2$. This is done by the mutual inductance M. The procedure is therefore to successively adjust R_2 and M until the galvanometer shows no current. It can then be easily shown that the ratio of the currents is

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* For a resume of these methods and a bibliography, see *Bulletin*, Bureau of Standards, Vol. VII, p. 423, 1911, reprint No. 164.

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \frac{1}{\cos\theta}$$

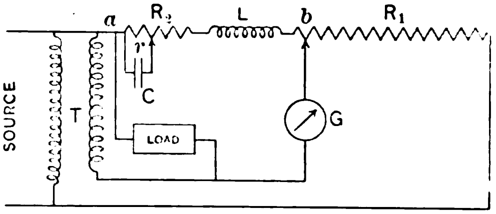

FIG. 2

and the phase angle is

$$\theta = \tan\theta = \frac{P\,M}{R_2} \text{ radians} = 3438 \frac{P\,M}{R_2} \text{ min.}$$

In most transformers the factor $\frac{1}{\cos\theta}$ differs from unity by less than one part in 2000, and hence for most engineering work it may be omitted. It may be necessary, however, to correct the phase angle for the inductance of the shunts.

The connections for the potential transformer are somewhat analogous and are shown in Fig. 2. A high resistance R_1 is connected in series with a smaller resistance R_2 and a self-inductance L across the high voltage side of the transformer. The low tension winding is connected in a reversed sense to the points a and b of this resistance, the galvanometer G being in series with the low voltage winding. The procedure is to adjust R_2 (or better

R_1) and L until a balance is obtained. It can then be shown that the ratio of transformation is

$$\frac{E_1}{E_2} = \frac{R_1 + R_2}{R_2} \cos \theta$$

neglecting terms of higher order, and, assuming R_1 and R_2 to be non-inductive,

$$\theta = \tan \theta = P\,L \left(\frac{1}{R_2} - \frac{1}{R_1 + R_2}\right) \text{radians} =$$

$$3438\ P L \left(\frac{1}{R_2} - \frac{1}{R_1 + R_2}\right) \text{min.}$$

The adjustment for the phase angle may be made by a variable self-inductance in R_1 or R_2, or by a mutual inductance, or by shunting a variable amount of R_1 or R_2 by a condenser. This latter combination is sensibly equivalent to a negative self-inductance of magnitude $C\,r^2$. In practise it has been found best to use a self-inductance in a series with R_2. together with a condenser shunting a variable portion of R_2.

With this arrangement the effective inductance of the circuit is

$$L - \frac{C\,r^2}{1 + p^2\,C^2\,r^2}$$

and the resistance is

$$\frac{R_2}{1 + p^2\,C^2\,r^2}$$

The term $p_2\,C_2\,r_2$ is practically always negligible, compared with unity, so that $L' = L — C\,r^2$, and R_2 is unaffected by the condenser. The advantages of this arrangement are twofold. First, it is possible without changing the set-up to test a transformer in which the phase angle changes from leading to lagging, and second, the fixed inductance may be placed in a fixed position removed from the rest of the circuit where its stray field will not cause trouble in the galvanometer circuit. Also this stray field will be constant in direction, whereas a variable inductance would have to be within reach of the observer and the field due to its movable coil would vary in direction and be much more difficult to detect and eliminate.

Considerable difficulty was encountered in obtaining a sufficiently sensitive self-contained detector in the case of the current transformer. At first sight this seems surprising since one naturally associates instrument transformers with heavy currents and high voltages. The trouble arises from the fact that the entire performance of the apparatus depends on the magnetic properties of its iron core, and consequently it must be tested under exactly the conditions of use, and sensitivity cannot be gained by forcing an abnormal amount of power into the circuit for a short time, as is possible with condensers, etc.

For the current transformer, in order to obtain a sensitivity of 1 in 10,000 at one-tenth load, it is necessary to use a detector capable to responding to about 2 microvolts a-c. We obtain this sensitivity by using a vibration galvanometer of the Campbell type, the moving system of which was reconstructed largely in accordance with suggestions of Dr. Wenner. The moving coil consists of but 4 turns of No. 28 wire. The total resistance is 0.66 ohm. The sensitivity is such that at 25 cycles one microvolt gives a deflection of 0.5 mm. at a scale distance of one meter. A range of frequency between 40 and 80 may be obtained by varying the length and tension of the suspensions. For lower frequencies between 40 and 20 cycles the moment of inertia is increased by the addition of a brass washer which may be dropped on a tiny cone at the top of the coil, thus automatically centering itself.

The advantages of the method are that only a single instrument is needed for all ranges of transformers, but one observer is required, and neither a polyphase source of voltage, a phase shifting device, nor a rotating commutator is required.

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